10July2024

Sawah Technology アフリカ水田農法 (4) Principles and Theory: *Sawah* hypothesis (1) the platform for scientific technology evolution and *Sawah* hypothesis (2) the platform for sustainable intensification in watershed agroforestry (Africa SATOYAMA System)

T. Wakatsuk,[1] M.M. Buri[2], R. Bam[3], O.I. Oladele[4], S.Y. Ademiluyi,[5] S.E. Obalum[6] and C. A. Igwe[6]

[1]Life and Environmental Science, Shimane University, Matsue, Japan, Mail: wakatuki@life.shimane-u.ac.jp
[2]Soil Research Institute-CSIR, Kumasi, Ghana, [3]Crops Research Institute-CSIR, Kumasi, Ghana, [4]North West University, Mafikeng Campus, Mmabatho 2735, South Africa, [5]National Center for Agricultural Mechanization, Ilorin, Nigeria, [6]Department of Soil Science, University of Nigeria, Nsukka 410001, Nigeria

Content

1. Why could IRRI realise the green revolution in Asia in such a brief time in the 1960–70s? Why did IITA and AfricaRice adopt the same strategy as IRRI in 1970s, but more than 50 years later, SSA as a whole still cannot say that the Green Revolution has been realized?

Sawah Hypothesis (1) Even good scientific technology, such as good seeds, good irrigation systems, and good agronomic practices, cannot work without suitable farmland platforms, such as quality Sawah system platform of at least four or higher evolutional stage, that is, the three green revolution technologies never work without appropriate Sawah platform.

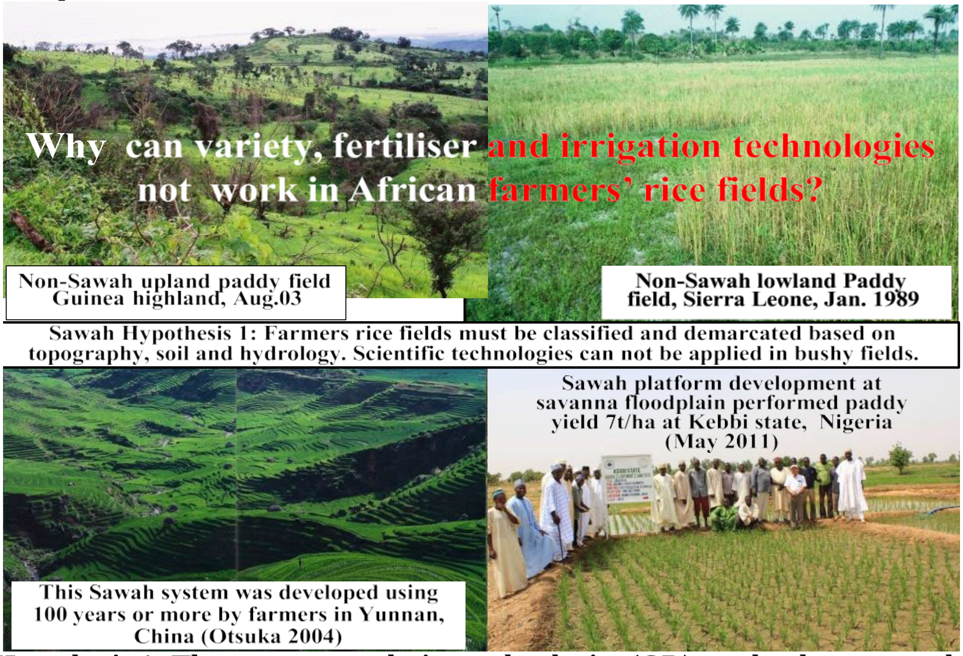


Fig.1 Sawah Hypothesis 1: Three green revolution technologies (GR) need at least an evolutional stage 4 Sawah platform. Two upper photos of Guinea highland and lowland of Sierra Leone show stages 0 and 1, respectively. Two lower photos at Yunan highland and Kebbi floodplain show stages 4 and 5, respectively.

A considerable paddy yield gap has existed between the African Research Institute (5–8 t/ha) and that of farmers (1–2 t/ha) for the past 50 years. Three major components of GR technologies (improved seeds, fertilisers and other agrochemicals, and irrigation) have been researched and developed during this period. Although they have been available in the experimental fields of various research institutes in Africa, these technologies have not been effectively adapted in African rice farmers' fields. Almost all institute-based technologies have not been scaled up to farmers' fields. Thus, the GR is yet to be realised.

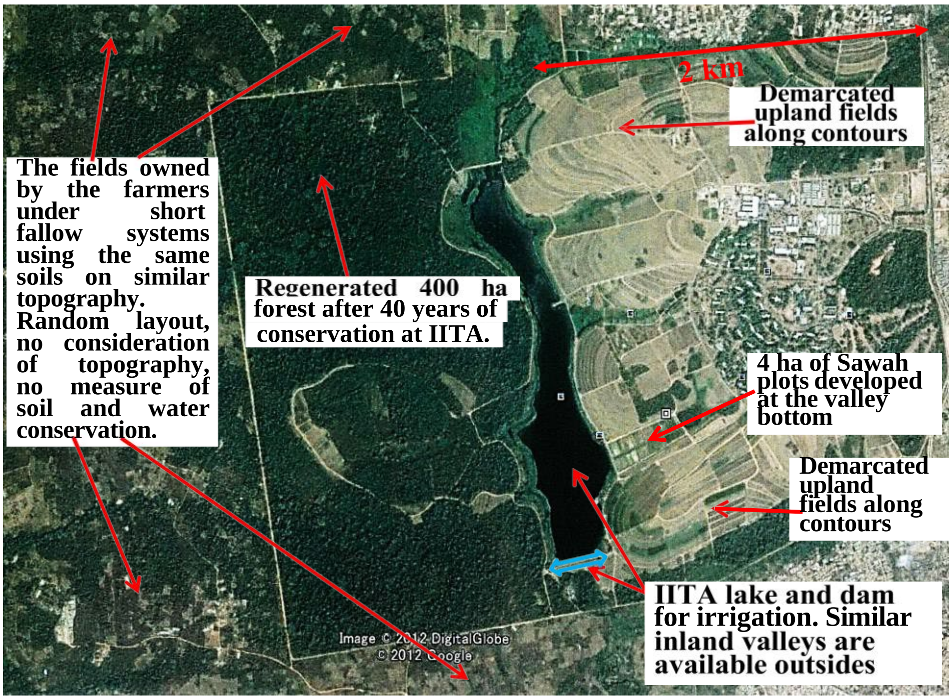


Fig.2. Sawah Hypothesis 1: A prerequisite platform to apply green revolution technologies exists in fenced 1000 ha IITA's research fields, but not the such land infrastructure in farmers' fields (central position: 7.494N 3.896E, photo taken in 2008).

Fig.3. Stage 4 and 5 irrigated Sawah platform at Mbe valley experimental fields of the headquarters of AfriaRice (Central location: 7.875N 5.116W)

Figures 1-5 explain the reason. *Sawah* hypothesis (1) for realizing a GR in Africa is that farmers' standard *Sawah* development, evolutional stage 4 or higher, should come first. We explain here that the core technology for a GR in SSA is *Sawah* ecotechnology (Wakatsuki et al. 1998, 2001a, 2005, 2009; Hirose and Wakatsuki 2002, Wakatsuki and Masunaga 2005, Oladele et al. 2010, Abe and Wakatsuki 2011, Igwe and Wakatsuki 2012).

2. Sawah Technology to develop a standard Sawah platform, the evolutional stages 4 and 5, both in small inland valleys and floodplains/inland deltas by farmers self-help efforts endogenously in SSA to realise the rice green revolution.

Figure 4 shows an example of Sawah technology application to many small inland valleys ecosystems in the Guinea Savanna and Equatorial Forest zones. In addition, although not tested, this technology can be applied to mangrove swamp ecosystems.

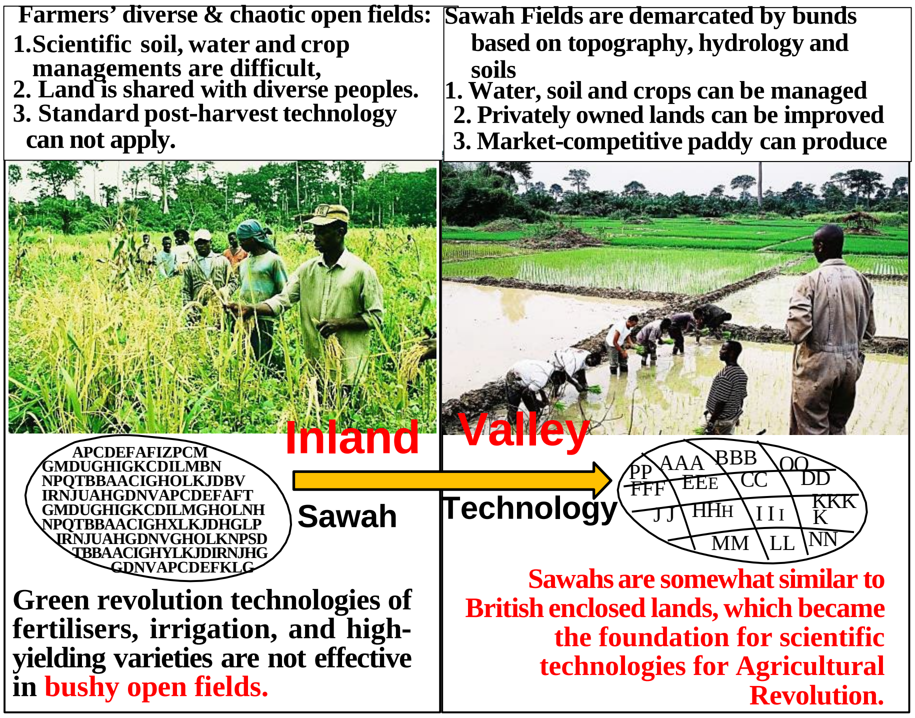


Fig.4. Sawah hypothesis (1) for Scientific Platform: Farmers' Sawah should come the first to realise Green Revolution. Farmers' fields must be classified and demarcated eco-technologically. Then scientific technologies can apply and evolve effectively. SSA's bushy open field systems have been long sustained till now. This might come from long history of slave/colonial rule in the 15th-19th century.

Figure 5 shows examples of Sawah technology application to the flood plains and inland delta ecosystems in Guinea, Sudan and Sahel savanna zones. **Sawah technology (5) Practices and potential** explains four key skills necessary to develop the sawah platform of evolutional stage 4 or higher. These four are (1) site selection and sawah system design, (2) power tiller-based efficient and low-cost sawah development, (3) sawah-based rice farming, and (4) farmers socio-economic empowerment measures.

Fig.5. Evolution of the Sawah System through the evolution of Sawah Technology at Kebbi State from 1987 to 2015. Non-sawah open rice fields at Arugungu in 1987 evolved into standard irrigated sawah system by sawah technology in 2011. After 2015, further improvement of Sawah platforms and more efficient development methods were created. As of 2023, more than 100,000 ha of Stage 4-6 irrigated sawah platforms have been developed through self-help efforts by Kebbi farmers.

As explained in the **Sawah Technology (2): Background**, rice farming can be improved by the synergistic effect of good seeds and good sawah platforms. All high-yielding varieties, such as IR-8 and ultrahigh-yielding hybrid varieties, have all been selected in the same growing environment as the irrigated sawah platform of evolutional stage 4 or higher in the research institutes such as IRRI, IITA, and Africa Rice. Since varieties such as upland NERICA were selected in a breeding environment such as sawah platform 0-2, it was a variety characteristic that could not increase the yield of > 4 t/ha in most farmers' rice fields. All rice varieties have some limited growing platforms. Therefore, in SSA, there is an urgent need to develop and disseminate easily scalable technology to improve the quality of the rice field platform of farmers, i.e., an evolutional stage of 4 or higher. Sawah Technology has been researched and developed in farm fields in Ghana and Nigeria from 1986 to 2015 with such a goal.

3. Quality of farm infrastructure (platform) determines the basic productivity: Sawah hypothesis 1 and Sawah hypothesis 2

It is very interesting to compare Japan's historical paddy yields and wheat yields from the UK during 1250–2014. Since the lowland sawah system has ecotechnological advancement, paddy yields had been higher, almost double, during 1250–1960 (Sawah Hypothesis 2). These periods include the 1st agricultural revolution period of the UK during 1700–1850 by enclosure and Norfolk Four Crops rotation. Japan's 1st agricultural revolution period was during 1850–1945. During this period, paddy yield increased from 2.5t/ha to 4t/ha. Since Japan had semi-dwarf varieties of rice and wheat before 1960 as explained in the Figure 18, chemical fertiliser technology from West was the major driver of this revolution. After Japan was defeated in World War II, Japan was hit by severe food crisis, and a rapid increase in paddy production became necessary. Improvement of irrigated sawah platform and mechanization, variety improvement, fertilization improvement, and disease and pest control with pesticides progressed simultaneously (2nd Agricultural revolution, i.e., Green Revolution in Japan). As a result, rapid increase of rice production was realized in 1946-1970, i.e., the average milled rice production in 1946-50 was 9.4 million tons (yield 3.24t/ha, 5t/ha on a paddy basis) and the average 1966-70 was 14 million tons (yield 4.3t/ha, 6.6t/ha on a paddy basis), achieving a self-sufficiency rate of over 100% (this can be said to be Japan's second agricultural revolution).

Although wheat yields in UK had stagnated from 1840 to 1940, the dramatic yield increase started and continued from 1940 to the date 2014. It was almost four times, 2t/ha to 8 t/ha. This trend, although 30-40 years advance, is almost similar to Asia's green revolution because the major driver was semi-dwarf wheat originating from Japan's Norin 10 and Akakomugi (Borojevic 2005). As seen in Figures 6 and 16, Japan's paddy yield became much lower than the yields of wheat in Europe and the United States after 1970s. In contrast to the US and European countries, all factors to increase paddy productivity have stagnated. Major factor was the policy, so called "*GEN-TAN* (Arahata 2014), i.e., reduction of paddy production by the reduction of cultivation area" policy, which continued during 1971-2018. The adoption of a breeding strategy that prioritizes taste even at low yields was encouraged. Productivity improvement or scale expansion of sawah-based rice cultivation was not recommended. Therefore, productivity also stagnated, as seen in Figures 6 and 16. The paddy yield in China has caught up with the paddy yield in Japan. This indicates that agricultural technology's advancement (improvement of yield) can be realised by cooperative work with biotechnology for variety improvement/evolution and improvement of rice growing ecology, i.e., ecotechnology for the evolution of *sawah* fields. As a matter of course, the essence of agricultural technology is an integrated use of technology for variety and growing ecology.

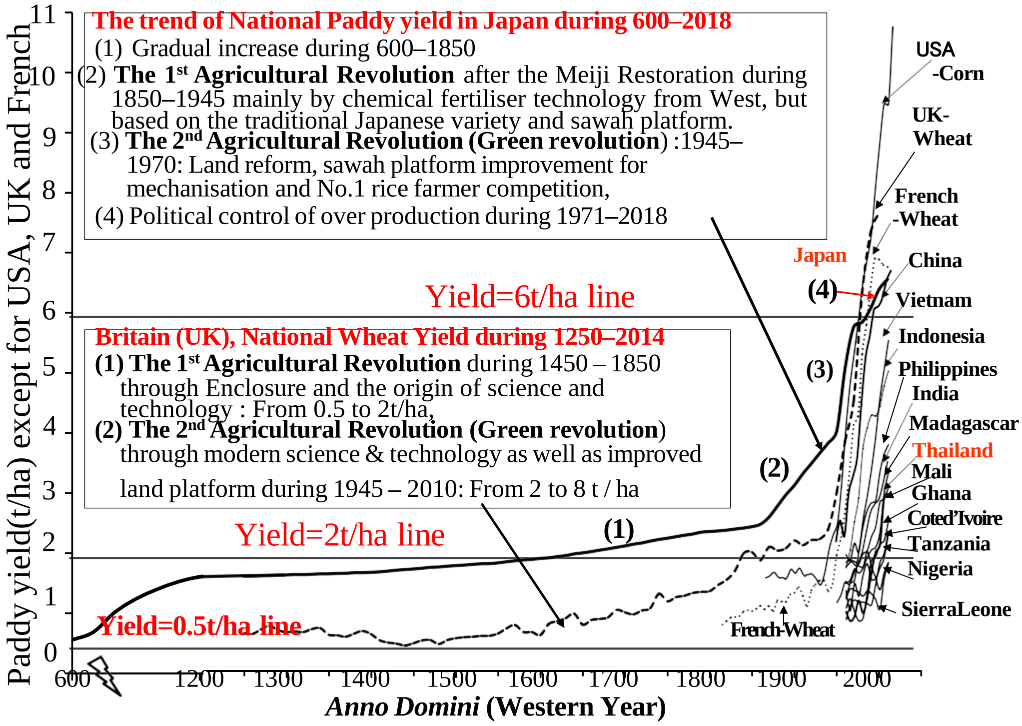


Fig. 6. Historical Trend of Core Crops' Yields of England, French and Japan during 1700-2014 as well as USA, Major Asian and SSA paddy producing countries (means of FAOSTAT 2017 and USDA 2017) during 1950 and 1961-2014. (Data Sources are Max Loser 2017, Overton 1996, Hopper 1976, Takase and Kano T 1969, and Apostolides et al 2008).

Comprehensive assessment of the above and following data, figures and photographs, that is, ① stagnation of the grain yield in Japan after 1975, ② the increase in the wheat yield in the UK, and ③ the high degree of intensive sustainability of the sawah system (Sawah Hypothesis 2) described in the next paragraph will enable to have the yield level of Japanese No.1 farmer, 12–16 t/ha, and No.1 prefecture, 11–13 t/ha during 1951–1968 (milled rice and paddy conversion ratio is 0.65, Honya 1989), with continuing relevant scientific improvement of both biotechnology and ecotechnology. Asian countries can achieve similar results as well. Therefore, it is necessary to normalise current agricultural research which is prejudiced in breeding research to balanced agricultural research of Bio-tech Eco-tech, including more balanced sawah system research for the future evolutional stage 7 sawah platform, for example, FOEAS (Fujimori and Onodera 2012) and Kebbi platform, which are described in **section 6-1 and 6-2 of Sawah Technology (3-1) Overview**. In addition, all the best national farmers during the national rice competitive years, 1951-1968, had improved their *sawah* system infrastructure on its efforts. They tried to improve and devise their *sawah* system and *sawah-based* rice farming suitable for their local environment and keep improving. Our *sawah* technology also emphasises farmers' self-help efforts and ingenuity. Therefore, agricultural research that makes use of farmers' ingenuity is important. If this yield level can be realised, no food crisis will occur even with 10 billion people on Earth. As can be seen from the fact that in Africa, even the present Egypt also achieves a paddy yield of 9 t / ha, if the irrigated sawah system suitable for Africa can be developed, since the sunshine in Africa is blessed more than Asia, somewhat lower soil fertility can be covered enough.

4. Sawah hypothesis (1): Similarity of Sawah system development and British Enclosure as a platform for Agricultural Revolution using Scientific technology

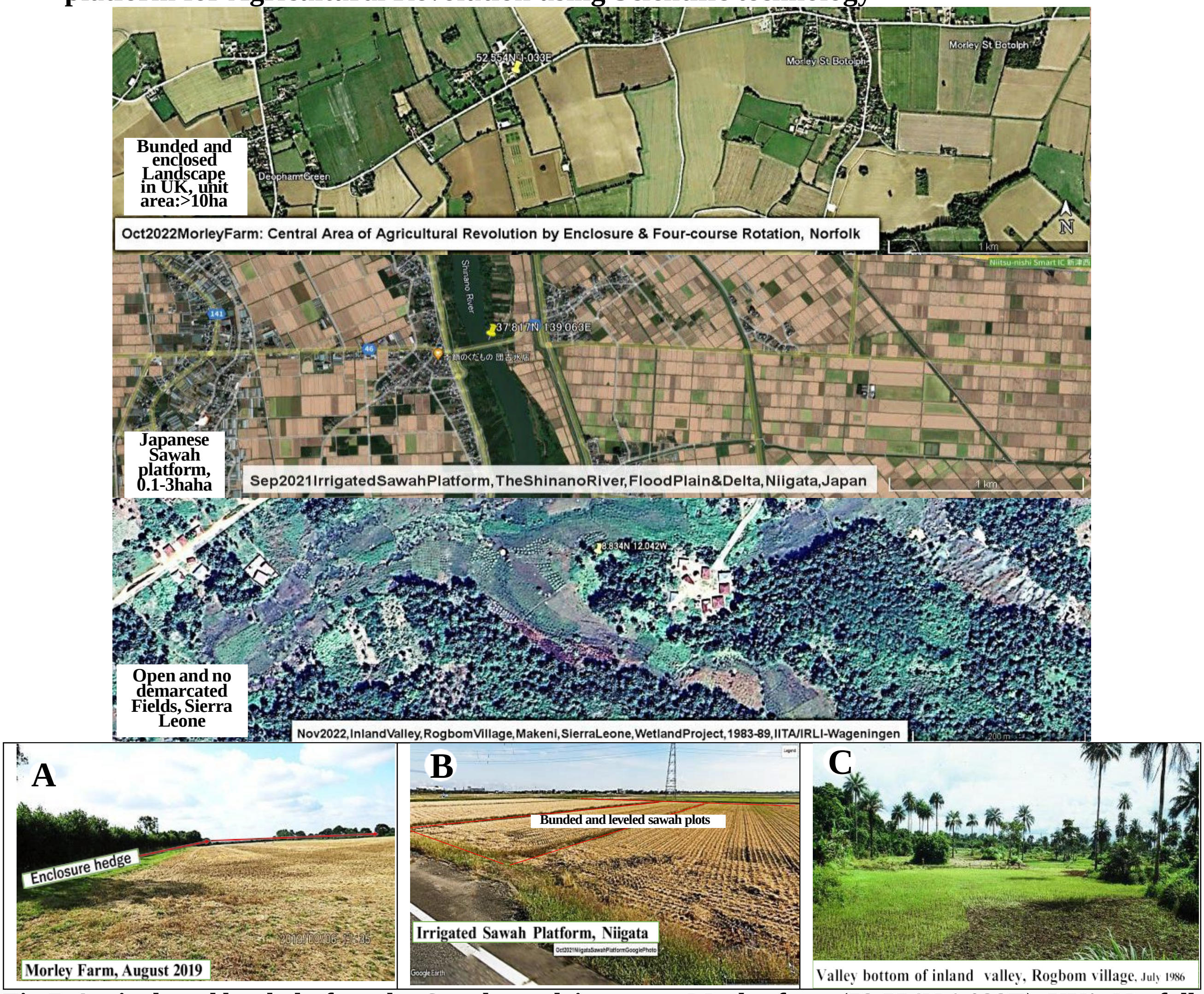


Fig.7. Agricultural land platform by Google earth images at Morley farm (52.554N 1.033E), UK's Norfolk wheat lands, rice lands in Niigata (139.063N 37.063E), Japan, and rice fields in inland valleys, Rogbom village (8.843N 12.042W), Makeni, Sierra Leone. Note that Google earth images' scale marker length of Norfolk, UK and Niigata, Japan is 1km, while Rogbom, Sierra Leone is 200m. Fig. 7A, B, and C show the ground truth corresponding to Morley Farm, Niigata flood plain, and inland valley of Rogbom village, respectively.

Fig. 7A photo was taken a Morley farm in August 2019, Fig.7 B shows a Google earth street view shot in October 2022 near 37.817N 139.063E in the Niigata Plain, and Fig.7 C shows a small inland valley growing rice in Rogbom Village in July 1987. The rice farming platforms shown in Google earth image in November 2022 and the photo in 1987 are showing largely unchanged in last 45 years. Wheat yield at Norfolk, UK, was about 8–10 t/ha, paddy yield at Niigata, Japan, was 7–8 t/ha, and paddy yield at Makeni was 1–2 t/ha in 2015–2020. As the evolutional stage of sawah platform in Sierre Leone was 0–3 and Niigata was 5–6, the difference of paddy yield between Sierra Leone and Japan was simply understood by Sawah hypothesis 1. Figure 7 explains the sawah hypothesis (1) and the similarity of sawah system evolution and British enclosure development and evolution as a platform for agricultural revolution using scientific technology. Both quality, i.e., at least stage four, sawah platform in Niigata, Japan (Asia) and British enclosure land are the platform for scientific technology to realize the green revolution. The inland valley at Rogbom village has no such rice growing platform. Thus green revolution technology cannot work, effectively.

A good distinction and levelling not only help to control water and conserve soils but also encourages the expression of the beneficial physical and biochemical interactions in upland or lowland soil. As shown in the various Google Earth images in Figures 1-5, and 7, the necessity for field demarcation and appropriate levelling is lowland and upland. Thus the Sawah Hypothesis (1) is equivalent to the British Enclosure. Although the quality of demarcation and levelling at the upland is not the same at the lowland. Figure 8-12 shows that good drainage to avoid surface runoff and the anaerobic root zone is critical in wheat cultivation in Norfolk, UK. In contrast, lowland bunding, demarcation and levelling are more critical than upland because of the difference in water flow power and physiological properties of rice plants with a breathable root system. Water control in farmers' rice fields, for example, needs at least stage 4, standard *sawah* systems for appropriate transplanting practice. Most African farmers' fields are not ready to accept most scientific technologies developed at research institutes such as the IITA (Figure 2) and AfricaRice (Figure 3). The *sawah* system and sawah technology is the prerequisite platform condition for applying the three Green Revolution technologies (*Sawah* hypothesis 1).

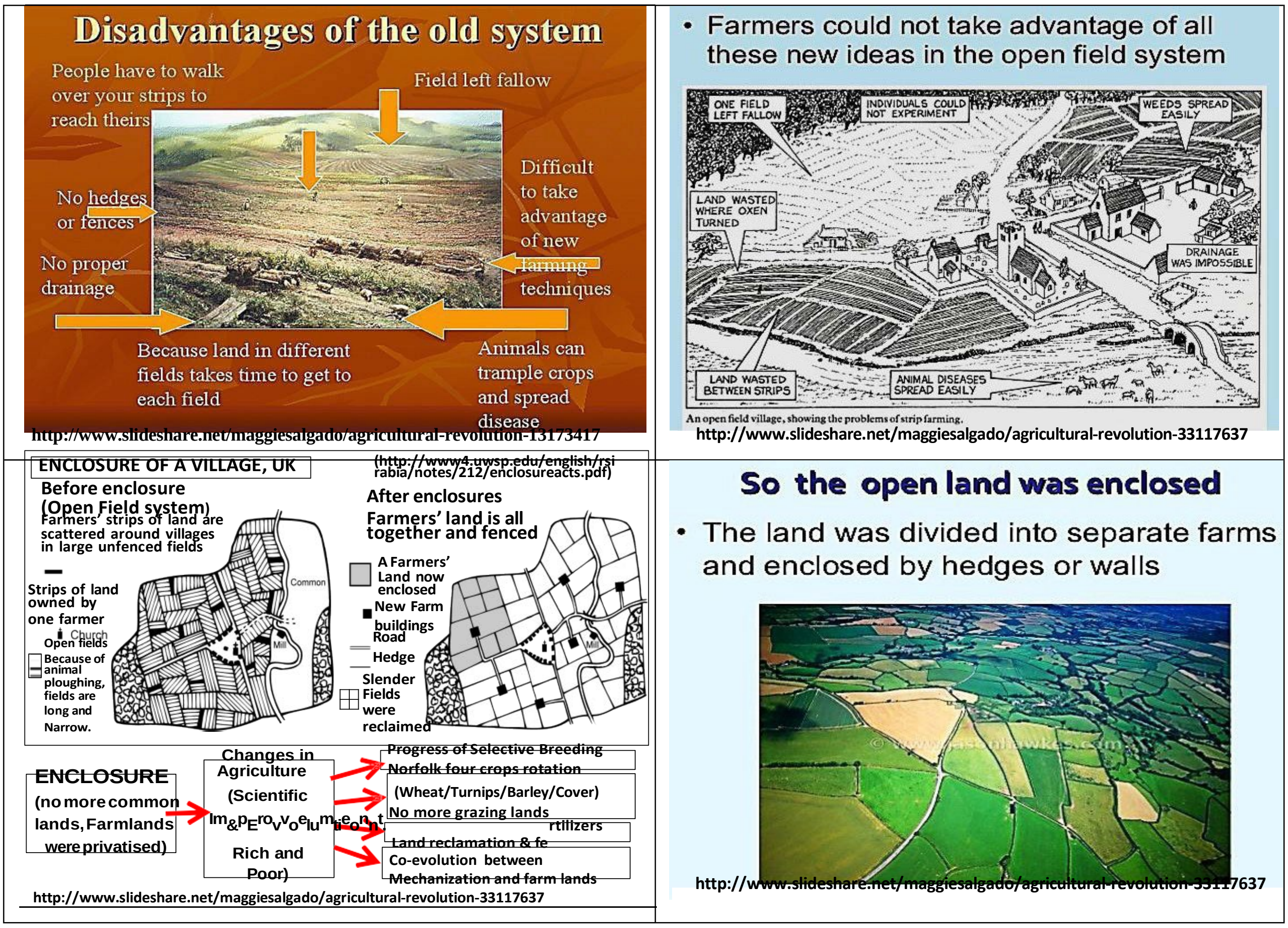
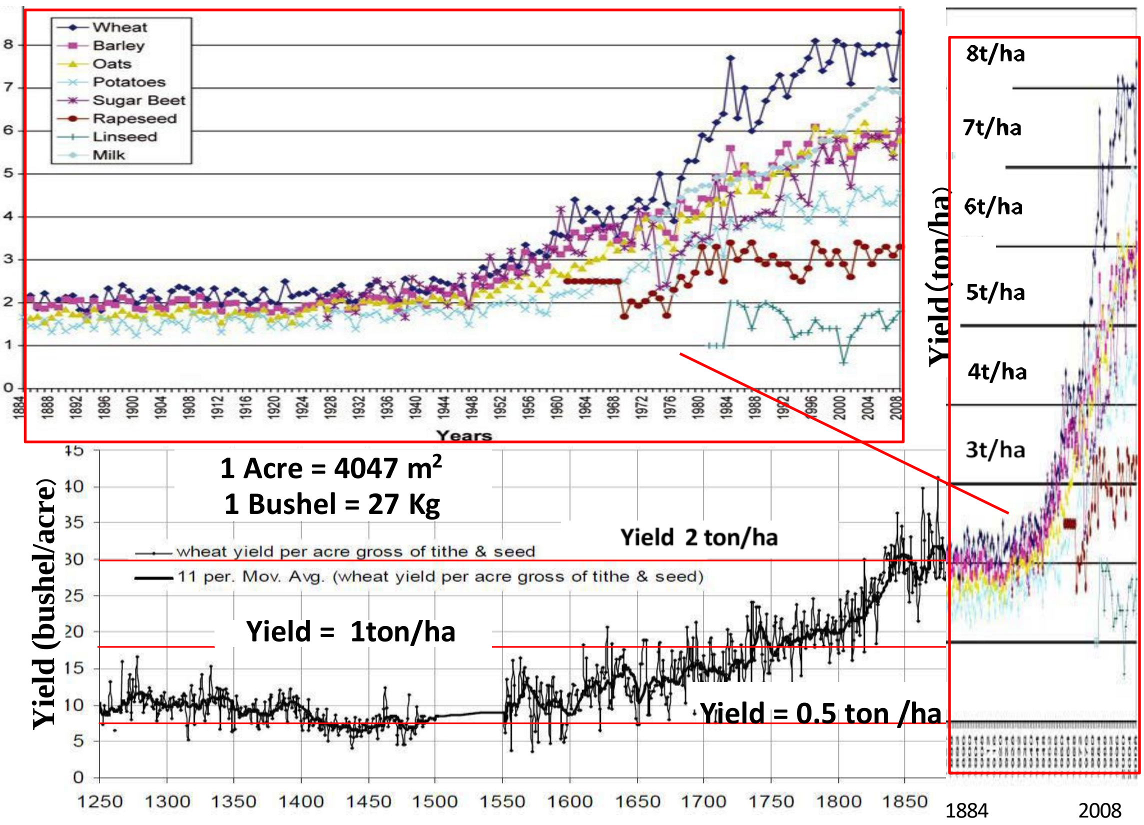


Fig.8. British Enclosure and Agricultural Revolution (Salagado 2012), possible relation to Sawah System Platform



(Data in 1884-2008 are cited Max Roser, 2017, Data in 1250-1990 are cited Apostolides et al 2008)

Fig.9. Increase in UK's wheat yields from 1250 to 2015+. The productivity of UK increased four times both in 1450-1850 (Agricultural Revolution 0.5 to 2 t/ha) and in 1930-2015+(Green revolution 2 to 8 t/ha). Yields of barley, oats potatoes, sugar beet, Rapeseed, Linseed and Milk are added during 1884–2008.

Table 1. A: Yield per acre gross of seed (bushels) and B: Seed sown per acre (Bushels) of Wheat, Rye, Barley, Oats and Pulses in 1250-1899 in England.

	A. Yield per acre gross of seed (bushels)					B. Seed sown per acre (bushels)				
	Wheat	Rye	Barley	Oats	Pulses	Wheat	Rye	Barley	Oats	Pulses
1250-1299	11.27	13.73	14.41	10.91	8.93	2.56	3.02	4.16	3.67	2.90
1300-1349	10.77	13.31	13.36	10.21	8.77	2.53	2.95	3.90	3.61	2.63
1350-1399	9.96	12.00	13.67	11.12	8.43	2.49	2.79	3.92	3.63	2.57
1400-1449	8.28	13.01	12.20	9.52	7.71	2.39	2.55	3.75	2.97	2.30
1450-1499	8.94	16.75	12.74	8.42	6.57	2.45	2.79	4.18	2.48	2.08
1550-1599	10.38	11.71	12.40	11.87	10.62	2.50	2.50	4.00	4.00	3.00
1600-1649	12.95	18.78	15.16	14.97	11.62	2.50	2.50	4.00	4.00	3.00
1650-1699	13.86	16.69	16.48	14.82	11.39	2.50	2.50	4.00	4.00	3.00
1700-1749	16.36	17.32	19.38	16.27	13.23	2.57	2.50	4.30	4.00	3.00
1750-1799	19.54	20.37	25.38	24.90	17.19	2.27	2.50	3.50	4.00	3.00
1800-1849	25.56	22.02	29.70	32.37	20.35	2.41	2.50	3.80	4.00	2.50
1850-1899	29.19	28.68	27.08	35.36	18.80	2.50	2.50	3.27	4.00	2.50

As shown in Figure 8 (Salgado 2012), medieval manors were characterized by open fields and rural communities. The period of modernisation progressed were also the age of enclosure, that is, the arable lands were enclosed with stone walls, bunds, or hedges, then reclaimed the enclosed lands. The first enclosure mainly in the 16th century was called "Sheep eat men (Thomas More's Utopia)", because the landowner evicted the tenant farmers to expand pastureland for sheep rising. Whereas the second enclosure around 1700-1850 dramatically increased agricultural production, as seen in Figure 9. The enclosed farmlands enabled reasonable land use plan and infrastructure development such as drainage improvement, the reduction of the wasteland, conservation of land degradations originating from cultivation, pests and weed management, promotion of selective breeding, new farming techniques and mechanisation. Furthermore, various scientific farming techniques were innovated (evolved) through field experiments that only became possible in enclosed lands. However, since the enclosures and infrastructure development needed investments, the rich capitalists who were able to carry out enclosure became increasingly rich and the tenant and the small farmers who were unable to enclose decreased agriculture income lost their land and became wage labourers at urban areas. Consequently, the gap between rich and poor increased. The wage labours were important for the **Industrial Revolution** and the development of the **Capitalistic society** (Kerridge 1967, Shiina 1982, Overton 1996).

Scientific technology is defined as the whole of knowledge, experiences, skills and practices that can be systematically and reasonably classified and categorised, thus transferring between human beings through learning, education and training. The enclosure was land demarcation, classification and rezoning practices. Agricultural science advances in the following three steps: (1) raising hypotheses, (2) verifying hypotheses through verifiable experiments and surveys, and (3) theorizing. Then in the next stage, paradigm, a new hypothesis is proposed. Such advances in agricultural science require classified research fields and classified demarcated enclosed farmlands. The modern Western world has only been materialized through the establishment of modern sciences (Chalmers 2013, Nakayama 2011, Butterfield, Seki 2016, Weinberg 2015). It may not be a rare coincidence that active period of contributors to establish modern science, such as Nicolaus Copernicus (1472-1543), Johannes Kepler (1571-1630), Galileo Galilei (1564-1642), René Descartes (1596-1650), Robert Boyle (1627-91), Isaac Newton (1642-1727), Antoine-Laurent de Lavoisier (1743-94), James Watt (1736-1819) and Justus Freiherr von Liebig (1803-73) had been overlapped with the period of Enclosure.

5. 2nd Agricultural Revolution (Green Revolution) and the Evolution of upland platform in UK during 1915–2016+ in comparison with Japanese ultra-high paddy yield during 1945–70

5-1. Comparative data on changes in agricultural structure over the last 100 years (1915/16–2015/16) between Norfolk, UK and Japan as a whole

Table 2. Comparative data on changes in agricultural structure over the last 100 years (1915/16–2015/16) between Norfolk, the birthplace of the British Agricultural Revolution, and Japan as a whole

The changing face of Norfolk farming	1915	2016
People working on farms	41,000	12,500
Hectares (ha) farmed	529,403	515,218
Horses&Tractors on Farms	59,703	3,000
Wheat (ha cultivated)	58,448	96,599
Barley (ha cultivated)	65,315	74,686
Permanet grass (ha)	115,304	53,435
Oilseed Rape (ha cultivated)	<3,000	30,962
Sugar Beet (ha cultivated)	<3,000	27,640
Potatoes (ha cultivated)	6,634	14,455
Clover etc. under rotation (ha)	60,455	11,962
Maize (ha cultivated)	<3,000	11,163
Field beans (ha cultivated)	4,269	10,003
Other vegitable(ha cultivated)	<3,000	7,554
Oats,turnips,Swedes,Mangold	98,800	<7,554
Cattle	129,081	74,130
Sheep	351,991	116,715
Pigs	117,429	539,201
Poultry	No data	15.5 million

(Finnerty 2018, Figures taken from the UK government's agric. surveys 1915,1950, 2016)

Japan's Farming 1916-2015	1916	1971	2015
People on Farm(million)	14	10	2.5
Sawah rice area (million ha)	**2.9**	**3.4**	1.7
Upland Crops Area(million ha)	**2.9**	2.4	2.8
PaddyProduction(million ton)	11	19	10
WheatProduction (million ton)	3	1	1.2
Cows (milion)	1.4	3.6	4.8
Horses (million)	1.6	0.1	0.02
PowerTiller(million)	0	3	<1
Tractor(million)	0	0.2	1.6
Pigs (million)	0.3	6.3	9.2
Poultry(million)	20	230	689

国勢社「数字で見る日本の100年」、Japan's 100 years in Statistics, revised 3rd ed 1991,pp542
農林水産省、日本の農業統計Ministry of Agriculture, Forestry and Fisheries (MAFF), Japanese agricultural statistics 2018
藤原辰史「トラクターの世界史」中公新書、2017

As shown in Table 2, in 2016, 515,000 hectares of farmlands were cultivated with 3000 tractors. In 1915, 529,400 ha of farmland were cultivated with 59,700 units of tractors and horses. Comparable Japan's data are as follows. In 1916, 5.8 million ha of farmland of both lowland irrigated rice and upland crops were cultivated with 3 million cows and horses. In 2015, 5.5 million ha of farmland were cultivated with 1.6 million small tractors (25-35 horse power). In 1971, 5.7 million farmlands were cultivated with 3 million walking power tillers (5-15 horse power)

5-2. UK's 2nd Agricultural Revolution (Green Revolution) in 1930-2010+: As with the Sawah platform in SSA, the importance of overlooked agricultural land platform improvement

Fig.10. Morley Agricultural Foundation and Morley Farms Ltd. Previously, this was the Norfolk State Agricultural Experiment Station (Google earth location is 52.555N 1.033E, Scale marker is 400m). The Annual Cropped area is 668 ha using three tractors, 165 hp, 200 hp and 300 hp, and 7.5 m header Combine harvester.

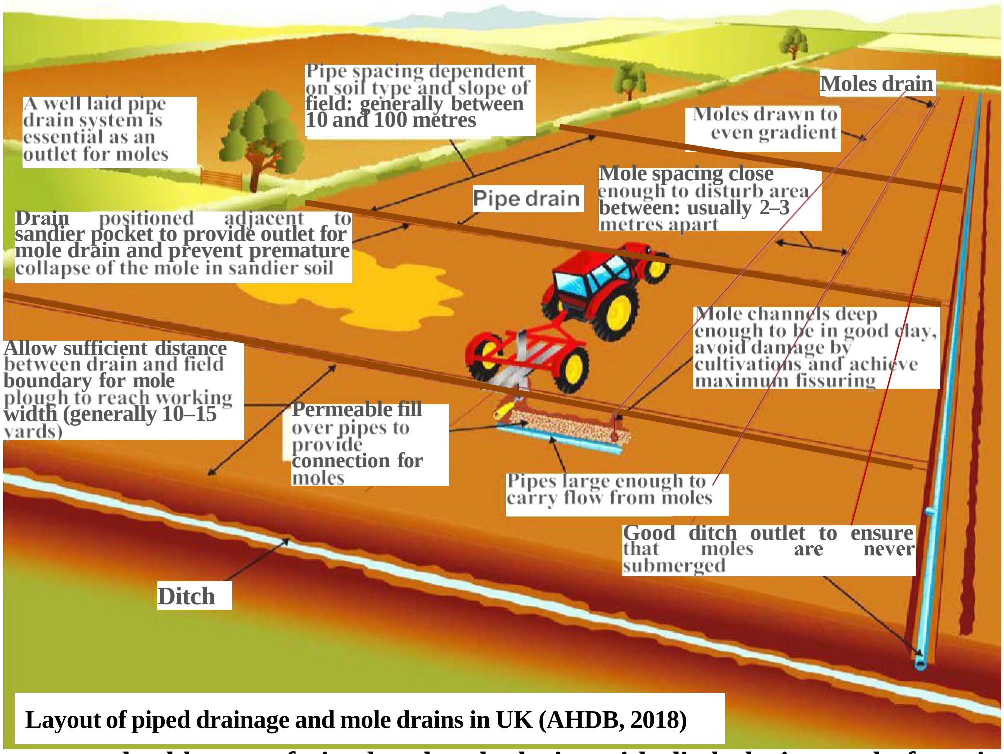
Fig.11. Norfolk upland platform for sustainability and diversity as well as ultra-high yield and large-scale mechanisation. The special target is to minimize surface runoff water to prevent soil erosion.

In August and October 2019, Wakatsuki, one of the authors, conducted a survey of Norfolk state, the centre of the UK's agricultural revolution in 1450–1850 and the modern green revolutions that have continued since 1930-to date. Figure 10 shows Google earth image of farm platform of Morley agricultural foundation. Three photos are farm office, harvester and 300hp tractor. According to farm manager, Mr. D. Jones (The Morley 2019), three tractors of 300hp, 200hp and 165hp can manage the cultivation of 668ha' farm. Typical yields were winter wheat 10 t/ha, winter barley 7 t/ha, spring barley 6.5 t/ha, sugar beet 82 t/ha, oil seed rape 4 t/ha, beans 5 t/ha, and dry peas 4 t/ha. These crops were put on best rotation in 4 years span. Annual total income was about 2 million$ (2800$/ha).

Figures 11A-11C show general farmland in Norfolk province around Morely Farm. Red lines indicate enclosure hedges. The photo of Fig. 11A shows a roll of wheat straw for fodder. The photos of Fig. 11B shows vegetable and Fig. 11 C shows black piles of manure. Most enclosed farm plots are 10ha or more, and the use of large tractors of 200 horsepower or more is essential. To make these large-scale mechanized farming sustainable and productive, it is essential to developed a proper drainage system (platform). The platform, which was the premise of the 2nd Agricultural Revolution (Green Revolution) in England, had a history of evolution and expansion of the drainage platform for about 100 years after 1900.

According to ADAS (2002), agricultural land in England and Wales developed 2 million hectares of pipe drainage schemes connecting with mole and ditch in 1960–1990. By 2018, the area has reached to 6.4 million hectares (70%) of agricultural land in England and Wales. Figure 12 shows current standard layout of piped and mole drains with ditch drainage platform in UK (AHDB 2018). One plot of farm land has approximately 100 cm (1 yard) deep pipe drainage systems at approximately 10-100 m (10-100 yards) interval, which are connecting ditch. Mole ploughs are run perpendicular to these drainage pipes to a depth of about 50-60 cm at intervals of 2-3 m. Permeable fill over pipes to provide connection for moles on top of pipes installed at a depth of about 1m.

These drainage platforms can control surface runoff water, surface ponding, waterlogging, poaching, and topsoil saturation manageable, dramatically improving farm business. Improved crop yield and quality, better access to land, efficient work, benefits to soil and environment, and reduced risk to livestock health (Robinson 1988, Robinson and Gibson 2011, Douet 2016, AHDB 2018). By intercepting run-off and trapping sediment before it leaves the field they help maintain and manage the provision of good water quality by preventing the loss of soil, chemicals, nutrients, especially phosphate, and faecal organisms. A further benefit is their ability to temporarily capture water and slow down flow for flood control (Environmental Agency, UK, 2020).



Layout of piped drainage and mole drains in UK (AHDB, 2018)

Fig.12. Current standard layout of piped and mole drains with ditch drainage platform in UK (AHDB 2018).

(A):Horse cultivation. Land which had fallen out of cultivation in the 1930s had to be restored as war became imminent. Barwick Hall Farm, Stanhoe, 1939-40.

(C): After the War, while many farms were still heavily depend on horsepower and large labour forces, others were ahead with mechanization. These Duo-Track ploughs fitted to crawler tractors were working in west Norfolk in 1950.

(B): Drainage was always a problem, here on water meadows in west Norfolk, but even more on the heavy, often neglected land in the south of the County. Wherever, it was back-breaking and long continued works, 1930s-1940s+.

Fig.13. Co-evolution between mechanisation from horse to tractor and land platform change from small enclosure land to well-drained big size land in 1914–1972 (Douet 2016) and in 1850–2019+.

Three photos of Figure 13 are cited from Mr. Douet's book (2016), "Breaking new ground, agriculture in Norfolk, 1914-1972". Figure 13A shows cultivation by horse common before 1950. Land which had fallen out of cultivation in the 1930s had to be restored as war became imminent. Figure 13B shows manual works for installation of drainage pipe in 1930-1940s. Drainage was always a problem in west Norfolk, but even more on the heavy, often neglected land in the south of the County. Wherever, it was back-breaking and long continued works. Figure 13C shows that after the War, while many farms were still heavily dependent on horsepower and large labour forces, others were ahead with mechanization. Tyhese Duo-Track ploughs fitted to crawler tractors were working in west Norfolk in 1950. Continuing efforts to improve farmland after 1950 led to large-scale post-war farmland improvement, the improvement and evolution of the Drainage platform, which laid the foundation for the realization of the UK's Second Agricultural Revolution (Green Revolution).

As shown in Figures 6 and 9, the British Enclosure Agricultural Revolution slowly increased wheat yields from 0.5 t/ha to 2 t/ha over about 400 years, 1450-1850. After that, for about 100 years from 1850 to 1950, it was stagnant at the level of 2t/ha. However, after World War I, 1914–1918, and World War II, 1936–1945, wheat yields increased dramatically from 2t/ha to over 8t/ha between 1950 and 2008.

5-3. Agronomic explanation of UK's 2nd Agricultural Revolution (Green Revolution) in 1930–2010

Figure 13 shows long term yields of winter wheat grain, 1852–2016, showing selected treatments, important changes in management and cultivars grown in Broadbalk experiment site, Rothamsted Research Farm (Johnston and Poulton 2018). Figure 14 shows Google earth image of the farm drainage platform of the Broadbalk site in December 2006 (51.812N 0.376W). According to the supplement to the paper in Johnston and Poulton (2018), similar long-term experiments had been continued since 1876 at the Woburn site, 100 km northwest of Rothamsted. However, in 1966, very intense rainfall resulted in surface runoff, severe gully erosion and the transfer of soil between plots and the experiment had to be abandoned.
Based on the above, the drainage platform at the Broadbalk site seems to have been improved to the similar standard drainage platform shown in Figure 12 after 1968. However, the Johnston and Poulton 2018 Supplement does not describe the improvement of the drainage platform in the test plot. The supplement by Johnston and Poulton (2018) described that, in 1968, the site was set up as it is now (10 sections divided into 0 section on the

left end and 9 section on the right end, and these sections were further divided into 18 columns) and subjected to long-term experiments. The size of the compartments is about 30mx6m except for the 0th compartment.

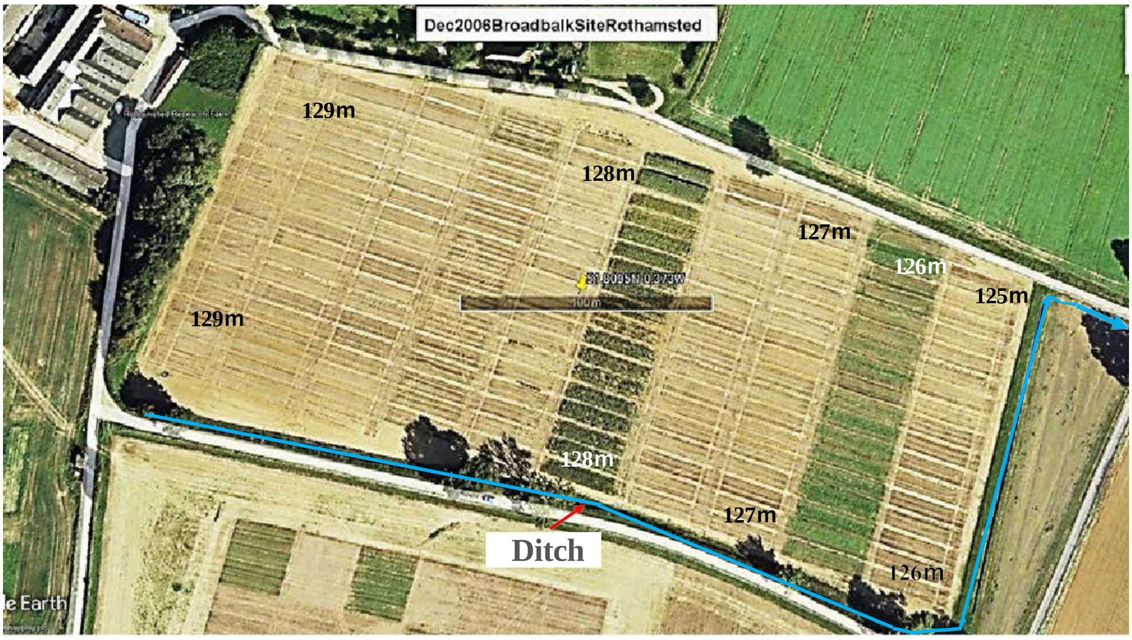


Fig. 14. Google earth image of the Broadbalk wheat experiment site in December 2006. Numerical figures of 126, 127, 128, and 129 are soil surface altitudes in meters read from Google earth image. Blue line shows ditch to drain water. Please compare the Fig. 12

The winter wheat yield pattern from 1852 to 2016 shown in Figure 15 is strikingly similar to the overall UK wheat yield pattern from 1850 to 2016 shown in Figures 9 and 16. A closer look shows that in the 80-90 years from 1850 to 1930–40 in the UK as a whole, the yield gradually increased from the level of 1.7-2t/ha to the level of 2.5t/ha. After that, it rapidly increased to the level of 7-8t/ha in 70 years until 2000. On the other hand, at Broadbalk site, the world's first fertilization test site, in 1852, the NPK fertilization plot marked a yield level of 2-3 t/ha, and in the 90 years until 1960, it very gradually increased to the level of 3 t/ha. It is noteworthy that in the 60 years since then until 2016, it has rapidly increased to a level of 10t/ha.

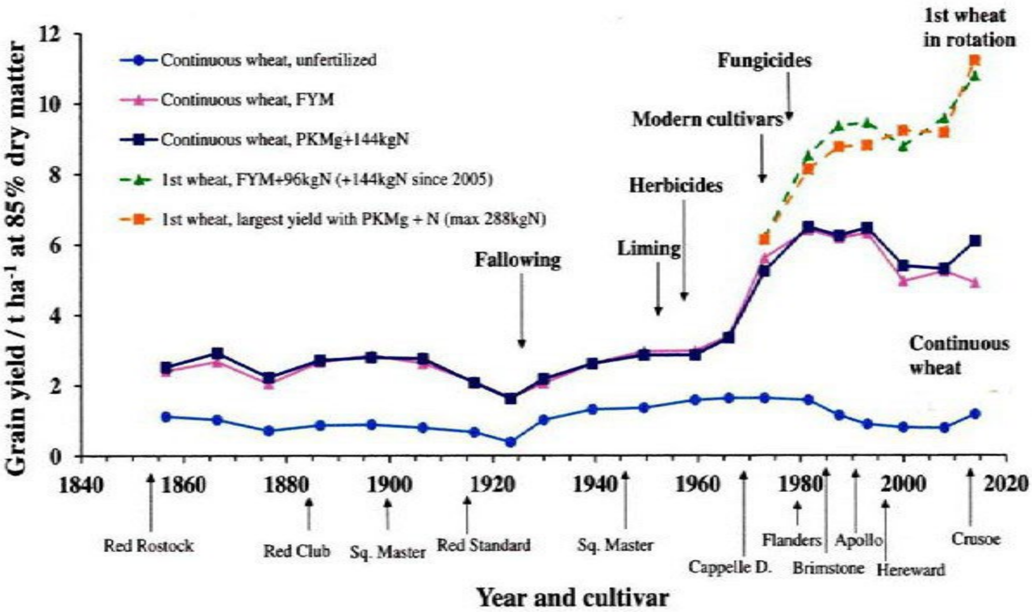


Figure 15. Mean long-term yields of winter wheat grain, 1852–2016, showing selected treatments, important changes in management and cultivars grown, Broadbalk Winter Wheat experiment, Rothamsted (Johnston and Poulton, 2018)

Like the Green Revolution in Asia and Latin America, the causes of the rapid increase in the UK after 1930-40 (2nd Agricultural Revolution = Green Revolution) are (1) the use of chemical fertilizers and pesticides, and (2) the spread of dwarf high-yield varieties, (3) the progress of mechanization, and (4) the development and evolution of farmland platforms that support those agronomic technologies. Drainage systems are important for the evolution of wheat farming platforms in the UK, and irrigated sawah system platforms are important in the case of rice cultivation in Asia. The Broadbalk site in Figure 15 states that the quality and quantity of fertilizers and various agricultural improvement techniques such as herbicides, modern cultivers, fungiciedes, and crop rotation are factors that have improved wheat yields (Johnston and Poulton, 2018).
However, we have to note that as shown in Figures 12–14, agricultural land platform improvement efforts, mainly drainage improvement, have continued for more than a hundred years since 1850 to date, which is the foundation that made it possible to apply these various good agronomic practices. In the case of the Broadbalk site, a modern drainage platform was constructed after 1968, which is believed to have contributed to the effective use of modern science and technology in (1)-(3).

5-4. The 2nd Agricultural Revolution of Japan in 1945–1970

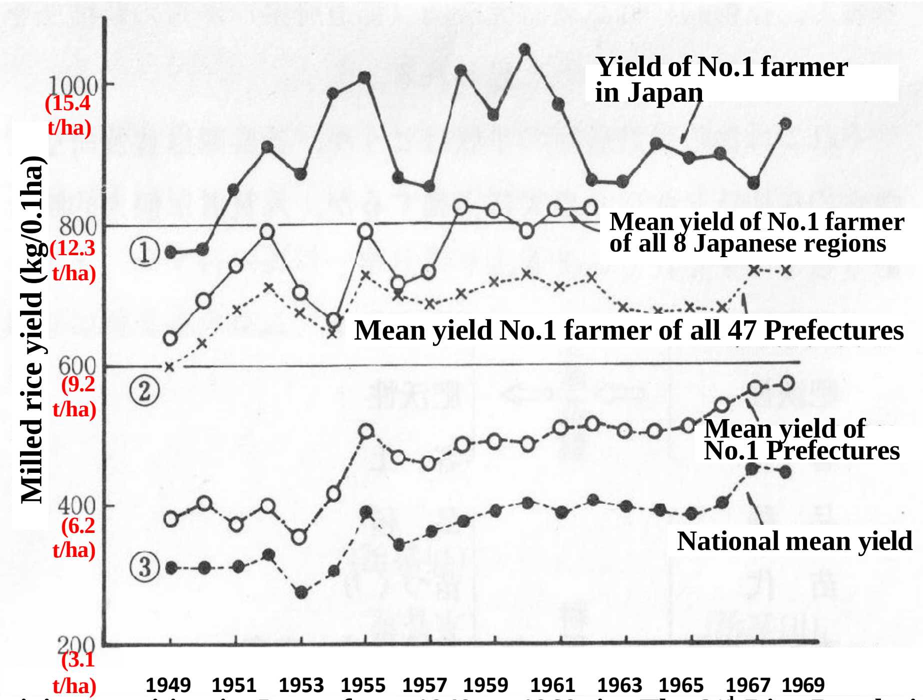


Fig. 16. Productivity transition in Japan from 1949 to 1969, i.e.,The 2nd Rice Revolution: ③ National mean yield, Mean yield of No.1 Prefecture, ② Mean yield of No.1 farmer of all 47 Prefectures, Mean yield of No.1 farmer of all 8 Japanese regions, and ① Yield of Japanese No.1 farmer (Honya 1989, ①-③ cited from Asahi News Paper 1971)). Paddy yield ton/ha are shown in red figures using equation of 0.65xPaddy rice= Milled rice.

Figure 16 shows the results of rice farmers' competitive policy to improve productivity, which the Japanese government strongly promoted for 25 years until 1970 after World War II in 1945. It shows the results of competing for the average yield of each of the 47 prefectures and the highest paddy productivity of individual farmers in Japan. The average paddy yield of No. 1 prefecture increased from 6t/ha to 9t/ha during 1949-1969. Therefore, the average rice yield in Japan increased from 4.6 t/ha in 1949 to 6.9 t/ha. The data of the highest paddy productivity in Japan for each farmer varies, but the yield was as high as 14 t/ha in ten year after the Second World War in 1955.
According to Honya (1989), who summarized the technology of Japan's No. 1 rice cultivation competition for 20 years from 1949 to 1969, the technology required to achieve an ultra-high yield of 12 tons/ha or more of paddy can be roughly divided into two categories of technology. (1) One is the improvement and evolution of the production base of rice fields, that is, the improvement and evolution of the Sawah system platform, and (2) the other is various cultivation methods, that is, the good agronomic practices. (1) includes followings, i.e., (a) the proper layout of the sawah system in the terrain chain, (b) realization of appropriate size and degree of

leveling of individual sawah plots, (c) installation of ridges without leakage, and (d) appropriate irrigation drains (gates), etc. In quite recent technology in Japan, smart agricultural technology for sawah (paddy or *TANBO* or *SUIDEN* in Japanese) rice cultivation in Japan has installed an automatically controlled water level gauge at the gates or valves of the sawah plot, centrally managing the water level of the sawah plots' surface with a smartphone, increasing both yields through optimum intermittent irrigation and strengthen the sawah dam functions (Minagawa and Miyazu 2021, Padich 2023).
A leveling degree of ±5 cm is a necessary condition for obtaining a paddy yield of 4 t/ha or more. Furthermore, leveling within ±2.5 cm is important for efficient weeding, and is necessary for direct seeding and SRI farming. Such water facilities with easy irrigation and drainage management are the foundation of high-yield platforms. If various good agronomic practices of the (2) are combined with this, a paddy yield of 10t/ha can be achieved. In addition to the above, the climatic conditions of high solar radiation higher than 17-20MJ/m2/month and the physico-chemical properties of the soil in the sawah plot are additional factors to achieve an ultra-high yield of 12t/ha or more. In terms of physical property, an optimum water percolation rate (or water requirement rate by Fukumoto and Shindo 2019), 20-30 mm/day (Yamazaki 1971) is very important. In order to control the appropriate percolation rate, such as 20-30 mm/day, appropriate drainage system of sawah plots is necessary. Figure 17 is an example by Yamazaki (1971), which is similar layout of UK's drainage system of wheat farm of UK as shown in Figure 12. FOEASA system (Fujimori and Onodera 2012), which is shown in Figure 32 of Sawah Technology (3-1), is also effective. In terms of chemical properties, ferric oxides rich red soil that promotes nitrogen fixation, silicic acid fertility enhancement, and high CEC clay on sandy soil. be. Of these, to maintain the percolate rate of 20-30mm/day is the key to manages appropriate redox potential of sawah plot (paddy) soil in Japanese condition, which is enabled to control of various microbial activities (control of nitrogen and phosphorus availability as well as soil carbon sequestration), and achieves ultra-high yields (see Sawah hypothesis 2 for details).

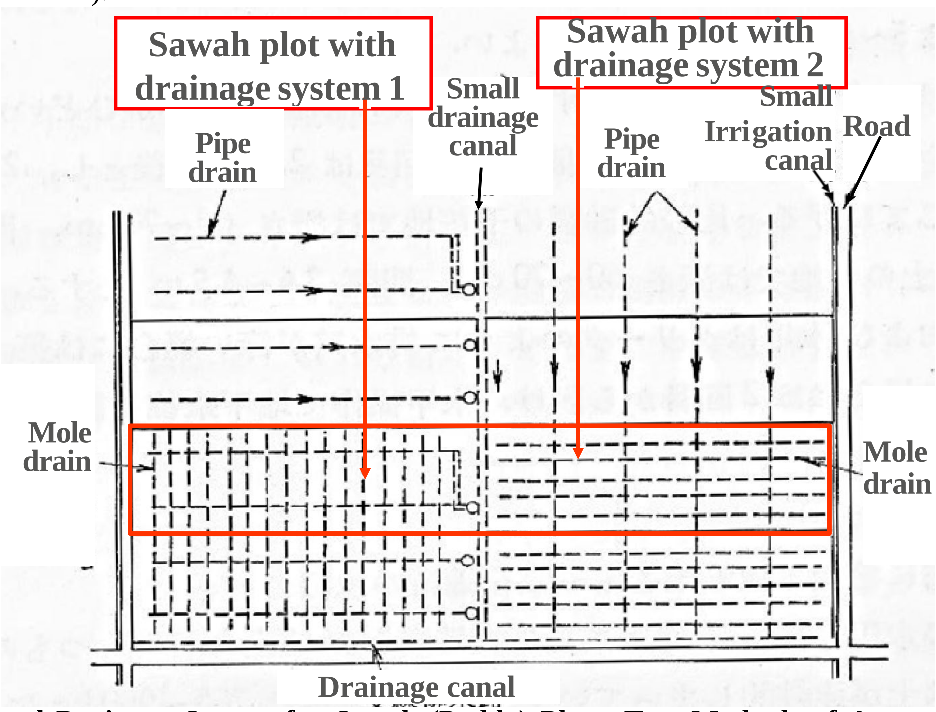


Fig. 17. Standard Drainage System for Sawah (Paddy) Plots: Two Methods of Arrangement of Pipe Underdrain and Mole Underdrain (Yamazaki 1971)

6. Sawah ecotechnology strategy to realize SSA's rice green revolution

Asian Sawah systems had developed by farmers using historical years of hundreds- thousands of years before scientific technologies were applied. Sub-Saharan Africa must accelerate its development within 40-50 years before 2050. Research, development, and innovations are necessary. Asian farmers had more than 60% of their rice lands in evolutional stage 4 in 1960-70 when the green revolutionary technology (GR) became available. But there have been less than 30% such platform in Sub Saharan Africa in 1961-2020 (as shown in Table 1a and 1b in Sawah Technology (1): Statistics). Figure 18 shows hypothetical modeled contribution of three agronomic green revolution technologies (high-yield breeding varieties, HYVs, irrigation, and fertilizer/pesticide) and sawah platform development during 1960-2050. This model is based on the quantitative contribution observed in Asian green revolution in 1965-1980 (Please see the Table 3 and Figure 16 in Sawah Technology (2) Background, (Herdt and Capule 1983). The contribution of agricultural land infrastructure improvement technology, i.e., sawah technology, which has not been evaluated. It is also a graphical representation of the **Sawah Hypothesis (1).** Bold lines during 1960-2005 are mean rice yield by FAOSTAT 2007. Bold lines during 2005-2050 are the estimation by the authors. It compares three Agronomic practices in Asia and the role of the sawah practice (technology) where these techniques can be effectively used with SSA. The rapid development of rice cultivation in the SSA after 2005 was driven by the evolution and expansion of the irrigated sawah platform. It is expected that rice cultivation in SSA will develop exponentially through synergistic effects of sawah platform improvement/expansion and good agronomic practices.

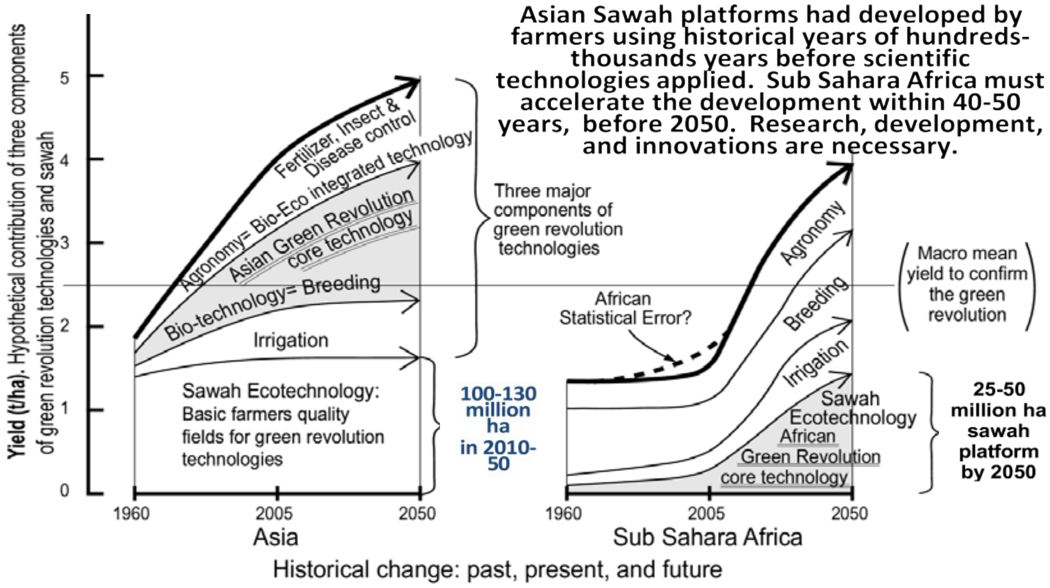


Fig. 18. Sawah ecotechnology strategy to realize SSA's rice green revolution

7. The historical path of Japanese and world population, sawah area and paddy yield increases in comparison with Major Asian and Sub-Saharan African countries

As shown in Figures 18–20, Asian *sawah* systems platform were developed over the past hundreds and thousands of years by farmers' self-support efforts, long before the advent of GR technologies. These are the basic infrastructures needed for applying HYVs, fertiliser and government-assisted irrigation technologies. However, such infrastructures are very limited in SSA. For various social and historical reasons, the endogenous developments of these basic land and infrastructure have been disturbed in SSA mainly by the globalization of the West, slave trade and colonization which started in the 15th century (Hirose & Wakatsuki 2002). Because of the rapid population increase, we must now accelerate the development of standard *sawah* systems to realise a Green Revolution. As shown in Figure 19–20, before the green revolution, there were long continued efforts to expand lowland sawah areas in Japanese rice cultivation during the 6th to 20th centuries**.** The same is true for other Asian countries, although various difference due to the degrees of disturbances by the globalization of the West (Fig 20). Figure 20 also shows the historical trends of paddy yield, sawah area and population of the historical path in Japan compared with paddy yields in major Asian and African countries. The historical trends of the world population are also shown in Fig.20.

Standards quality of the sawah system effectively utilizes water, nutrients and fertile topsoil gathered in the lowlands of the watershed area, as will be described later as Sawah hypothesis 2. Weeds can be controlled by water management of appropriate shallow flooding and drainage and appropriate puddling. Since geo-topographical and ecological nutrient supply amount to lowland sawah fields is higher than those of upland rice and wheat, the sustainable yield was higher during 1700–1900 (Figure 19), almost double before 1900, i.e., before the popularization of modern agricultural technology, such as chemical fertilisers became common (Sawah Hypothesis 2, Figure 24). The supporting data on the superiority of the lowland sawah system in comparison with upland rice are also clear in Figure 23 and Table 3. The historical changes in Japan's paddy yield and wheat in the UK were compared and shown between 1700 and 2014 in Figure 19. The wheat yield data in the UK shows 10 years of moving mean data in Figure 9. Figure 19 also shows the changes in the average yields of major rice countries in Asia and SSA during 1961–2014.

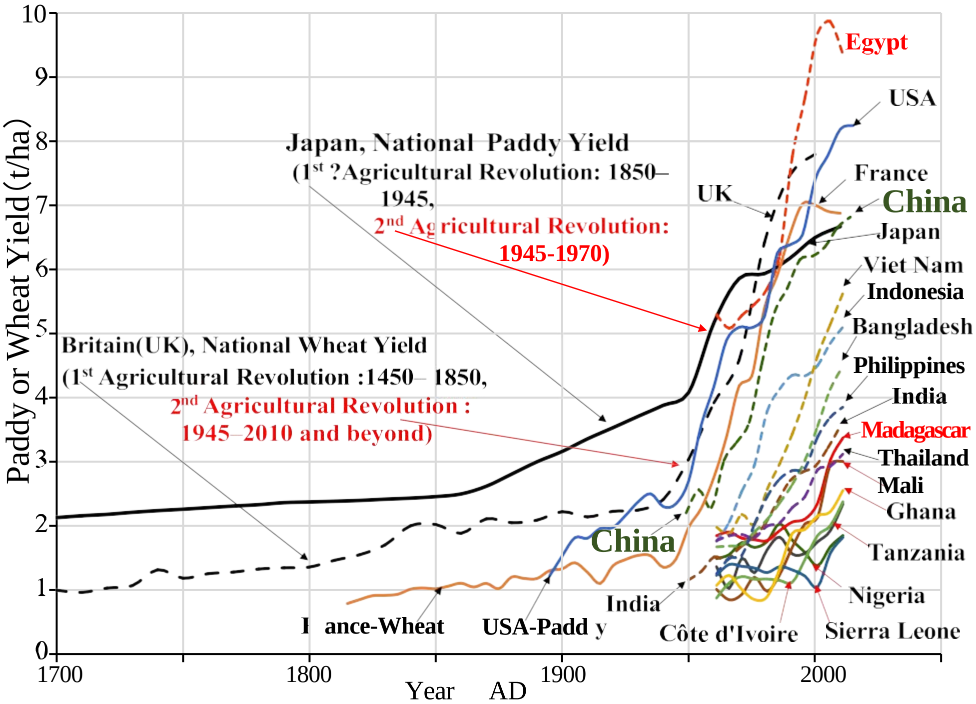


Fig. 19. Historical Trend of paddy yields of Japan during 1700–2014. Paddy yields in major rice countries in Asia, Egypt and SSA during 1961–2014 except for China (1949-2014). The wheat yields in England during 1700–2014 and French from 1830 to 2014 and the Paddy yield of the USA in 1880–2014

As shown in Figure 19 (data sources see Fig. 6), as already mentioned, after Japan, the paddy yields of Asian countries, China, Viet Nam, Indonesia, Bangladesh, Philippines, and India, have increased rapidly since 1961 by the green revolution technology. The most recent 6 years (2016-2021) mean paddy yield in t/ha and production in million tons per year by FAOSTA (2023) are as follows, China (7.0t/ha, 210milion tons per year), India (4.0 and 178), Indonesia (5.1, 55.4), Viet Nam (5.8 and 43.3), Bangladesh (4.7 and 54.2), Philippine (4.0 and 19.0), Thailand (3.0 and 31.6), and Japan (7.2 and 10.6).
After 2000, top group countries have been increasing their national mean paddy yields, such as Madagascar and Mali which have a higher ratio of standard irrigated sawah platform stage 4 than the other countries in SSA. Madagascar and Mali are now in 2014 similar national paddy yields to Thailand. The country's average yield is increasing, such as Ghana, Tanzania, Ivory Coast, coupled with the sawah system development and improvement. In contrast, Nigeria and Sierra Leone's yield increase is delayed because most sawah system platforms in these countries are behind the standard stage of sawah system evolution 4. The most recent 6 years mean paddy yield in t/ha and production in million tons per year in 2016-2021 by FAOSTAT (2023) are as follows, Nigeria (2.3t/ha and 9.5 million tons), Egypt (9.3 and 4.6), Madagascar (2.7 and 4.0), Tanzania (2.8 and 3.2), Mali (3.3 and 2.9), Corte D'Ivoire 2.7 and 1.9), Guinea (1.3 and 2.3), Senegal (3.5 and 1.2), Sierra Leone (1.2 and 1.4), and Ghana (2.9 and 0.89). It should be noted that among these SSA countries, rice production has stagnated in Madagascar in the last 10 years (2012-2021) and in Core d'Ivoir in the past few years (FAOSTAT 2023).

Because the sawah platform had been developed and sawah-based farming had been practised, Japan's 1st Agricultural revolution was realised immediately after the introduction of fertiliser technology of the West at the end of 19th century. Then the rapid expansion of irrigated sawah platform was followed based on pump irrigation and drainage, with the rapid population increase, which finally, unfortunately, exploded as the world war the II. Although world war the II was the biggest human disaster in world history, very fortunately, colonized major Asian countries could get independence in 1950s and then African countries could follow in 1960s.

The most recent 6 years (2016-2021) mean paddy or wheat yield in t/ha and production in million tons per year by FAOSTAT(2023) are as follows, USA paddy (8.5t/ha and 9.3 million tons), UK wheat (7.9 t/ha and 14 million tons) and France wheat (6.8 and 35 million tons).

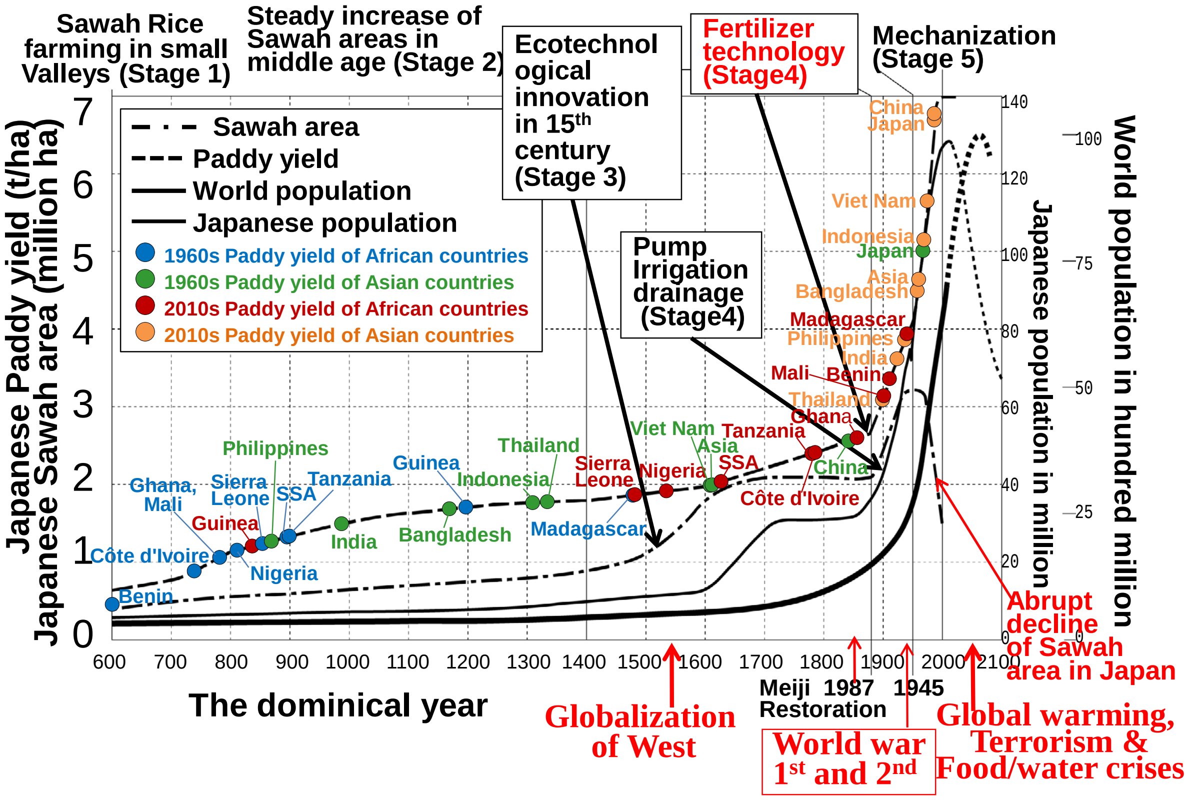


Fig. 20. Historical path of Japanese and world population, Sawah area, and paddy yield in comparison with Asia and Africa based on FAOSTAT data. (Takase and Kano 1969, Honma 1998, Takase et al 2003, Kito 2007, Wakatsuki 2013b)

As seen in Figure 20 for the trend of Japan, however, only 10-20 years after world war the II, because of the expansion of the economy, through science and technology innovation-based industrialization and urbanization, agriculture was declined and thus the sawah area had decreased rapidly. Therefore, after the Japanese population maximum reached in 2008, decline and ageing population is the major problem now. In contrast, majority of Asian and SSA especially are expecting rapid population explosion and maximum within decades with possible world crises on global warming, terrorism, and food and water shortage.

If we take a closer look at the stages of lowland sawah development in Japan in Figure 20, we can distinguish five stages, that is, (Stage 1): BC10th to 7th century: Sawah development in various lowlands, which have hydrology of easy water control, such as small inland valley streams and springs (Stage 2): 7th to 15th century: Steady increase of sawah development in bigger lowland and bigger river water sources (Stage 3): 15th to 19th: Major ecotechnological breakthrough to control major flood plain of major rivers (Stage 4): 19th to 1960s: Introduction of scientific fertiliser technology of the West. Pump irrigation and drainage made it possible to develop big swamps, typically delta (Stage 5): 1960s to date: Mechanization and major sawah reclamation for efficient mechanized operation.

In Sub-Saharan Africa, we can now available all basic technologies used at all five stages. The only major lacking is farmers' skills on sawah technology and sawah system infrastructure/platform. Therefore, if African farmers master the skills of sawah technology, lowland development and irrigation projects will be accelerated to achieve the rice green revolution, hopefully by 2025-2030.

8. **Beyond Realizing African Green Revolution: Theoretical Consideration of Sawah Hypothesis (1) and Ultrahigh Sustainable Rice Yields Level Achievable in Near Future by 2050.**

Figure 21 shows the three major factors of productivity growth using production functions by Kalaitzandonakes et al. 1994). The total productivity can be arranged into three major factors., ① elimination of inefficiency, ② Scale adjustment, i.e., expansion to the appropriate scale of farmland and management scale, and ③ advancement of technology. Please note it is an example of an extension by one of the authors (T. Wakatsuki) to add sawah hypothesis 1 as a cause of inefficiency elimination. The progress from A → B, or C → D are agricultural revolution by Paradigm/Regime shift, which is the agricultural intensification (Boserup 1965). Even if inputs such as labour, and output never increase, Geertz (1963) described shows the period of agricultural involution typically observed in sawah-based rice farming in Indonesia from 1900-1960, just before the green revolution. This may be described as internal development or sustainable agriculture. If we observe Figure 19, Japan's sawah-based rice farming during 1700–1850 was a similar involution period. The position of Boserup (1965), Geertz (1963) and Marthus (1798) were cited based on the paper by Ellis et al. (2013). However, these theories never reflected the rapid increase in productivity by modern science, such as the green revolution of 1960 – 2014.

Among these three factors concerning the realization of the green revolution (GR) in Africa, the Asian GR was high-yielding varieties (HYV) developed by international agricultural research centres, such as IRRI (International Rice Research Institute) and CYMMET (International Wheat and Maize Research Institute). However, due to too dramatic success, it seems that it was too overburdened with the advancement of technology, such as variety improvement by biotechnology, which is only one of the technologies of factor ③. The two curves shown by F1 and F2 in the figure are two production functions. The production function describes the general relationship between productivity (P), such as output (Y) or yield (Y), and various inputs when farmers produce rice by inputting labour and materials (L) to certain farmlands (R). Therefore, it is generalized that F1 shows what is due to the current farming system and F2 shows when it reaches a high-level production function due to technological progress (Kalaitzandonakes 1994, Watanabe 2010, Arahata 2014, and Sekine & Umemoto 2015).

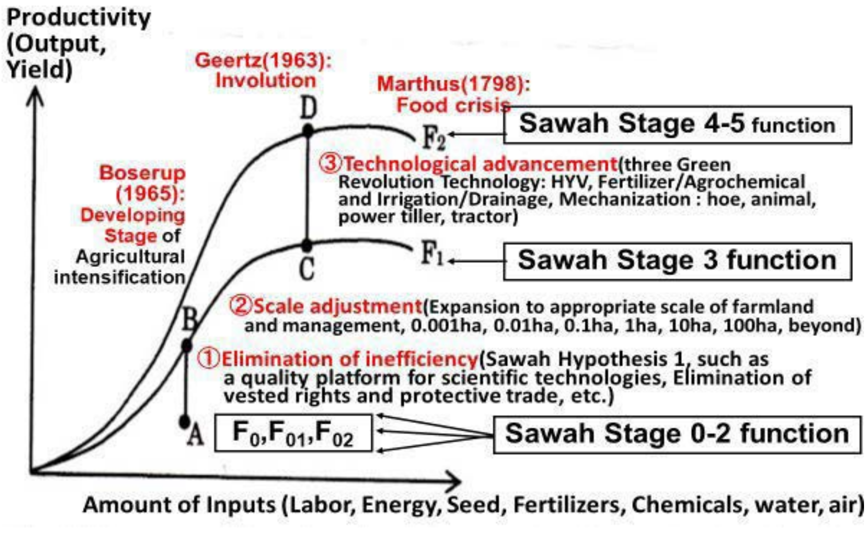


Fig.21. Decomposition of productivity growth using production function. Total productivity= ① Technological advancement +②Scale adjustment+③Elimination of inefficiency (Cited from Sekine and Umemoto 2015, Arahata 2014, Kalaitzandonakes 1994). (Explanation of various sawah platform stages were added by authors). Note of the citation of the Figure 21: Inclusion of Sawah hypothesis 1, Sawah stages 0-2, 3, and 4-5 function, Boserup (1965), Geertz(1963) and Marthus (1798) were done by T. Wakatsuki.

The first factor ①elimination of inefficiency is to reach the frontier of the production function F through eliminating base line causes of inefficiency (Arahata 2014). British enclosure during 1500–1850 removed such technical inefficiency to reach the level such production function which made the foundation of the Agricultural

Revolution (Kerridge 1967, Overton 1996). The enclosure changed the common shared lands by eliminating the medieval open scattered small strips unfenced (no demarcated) field system to privately owned fenced/hedged straight grouped larger lands, which formed the platform to change the long continued medieval agriculture and made begin various scientific improvement and innovation. Norfolk four crops rotation, wheat-turnips-barley-clover, has developed and been widely disseminated to improve soil productivity to convert the grazing land into a good crops farm lands, accelerate selective breeding, mechanisation and chemical fertiliser application. Looking at the current status of SSA, under the current multi-layered shared land right use system, irrigated sawah system development by either government or farmers' self-support efforts has been frequently challenged through the destruction of bunds, canals, dykes, weirs and surface levelling of sawah systems by nomads' cattle in dry season, and fisher men's traps. These are inhibiting the sustainable development and management of irrigated sawah systems.

The sawah hypothesis 1 mentioned in this paper is precisely the ① elimination of these inefficiencies. As shown in Sawah Technology (3-1) and Fig. 1-5 and 7, it is obvious that most current rice fields are difficult to control water in SSA even under irrigation. These are also similar to the British's medieval open small strips scattered in unfenced (no demarcated) field systems. Therefore, most rice farmers' lands in SSA have not reached the production function F1 frontier. Thus, three green revolution technologies of high-yielding varieties, fertiliser/agrochemicals, and irrigation/drainage are ineffective. As the ①elimination of inefficiency, in the case of SSA, measures concerning the quality of agricultural land similar to enclosure and Sawah system, the necessity of infrastructure platform, i.e., quality standard irrigated sawah system, is the main issues. However, in the other parts of the world where had already experienced the first agricultural revolution such as the green revolution, the main issue may be eliminating institutional inefficiencies such as stopping trade protection and encouraging free trade. In countries where priority have been given to industrial revolution rather than agriculture promotion like Japan in 1971-2016 and the current Asian countries since the period of high growth, ageing and lack of personnel, the productivity may not reach to the frontier of the production function (point B of F1 curve).

Looking back on the history after the independence of SSA since 1960, erroneous policies of "let's not have feet on the ground" were taken, which means that the industrial revolution the 1st without considering the agricultural revolution. This adverse effect remains in society as a whole, as a disregard of agriculture seen in young people and society in general.

The second factor is ②Scale adjustment in Figure 21. If it expands to the farmland of the proper scale, farm management of the appropriate scale becomes possible, and cost reduction becomes possible. When reaching point B on the front line of the production function F1, productivity can be increased from point B to point C by rice cultivation with a farm of an appropriate scale. In the *Yayoi* period of Japan, 2400-2500 years ago and the current SSA (Sawah Evolutional stages 0, 1,2, and 3), the number of agricultural lands of 1 ha is divided to 1,000-400 sections of micro rudimentary sawah of 10–25 m^2, and water management and soil management in each sawah plot are also practically impossible. Therefore, agriculture is in an extremely close position at the origin of the coordinate axes of the production function F1. Therefore yield, remains low. Even if the scale of the sawah plots is increased, the quality of the sawah field is low (topographically irrigation and drainage is not easy, leakage from bunds of sawah plots, insufficient levelling of sawah soil surface, rice planted on ridge, water leakage from sandy sawah soils, etc.), cost reduction will not be realised. Also, if it is too large, it takes time to irrigate and drain, making it difficult to manage water control. In current Japan, after 2018, the scale expansion and the expansion of the area of one sawah field are in progress, but as in the US and European agriculture, one unit of family farm land of 10 to several 10 ha and total farm land 100–1000 ha of one farmer's management is not the proper scale, probably appropriate area of one sawah plot is 0.5 - several ha, in terms of the consideration of optimum water management of each sawah plot, and total farm land of 10 - several 10 ha of one family farmer's management scale. It will be clarified in about 10 years. In Japan, maintenance and improvement of farmland of this appropriate scale and management of sawah field farmers, i.e., the ② scale adjustment and expansion has been stagnated for last 50 years due to the controversial policy to discourage rice production, since 1970. Therefore, productivity also stagnated, as seen in Figure 19.
The third factor ③Technological advancement is not the major problem in current SSA. If the other two factors can be satisfied as per the Asin farmers' level, reaching a national mean yield higher than 4 t/ha will not be a problem.

As shown in Figure 19, Egypt continues to have the world's highest paddy yield, 9–10 t/ha. Fortunately, in the Sahel zone of SSA, various wetlands similar to those in Egyptian Nile delta are distributed from the inland delta of Mali to South Sudan via the Lake Chad area on a scale of tens of millions of hectares. As described in Sawah Technology (3-1): Overview and Sawah technology (6): Kebbi Rice revolution, these regions are not difficult for countless farmers to develop small-scale irrigated sawah platform using groundwater, various rivers and lakes. It will not be difficult to realize stage 5-7 sawah platform development on a scale of 10 million ha by around 2050 through international cooperation and endogenous development by farmers and refugees under the support of the governments of SSA. As described in Sawah hypothesis (2), if Egyptian-style high-yield rice cultivation with carbon sequestration, sawah based rice farming can contribute to mitigate both global warming and the world's food crisis.

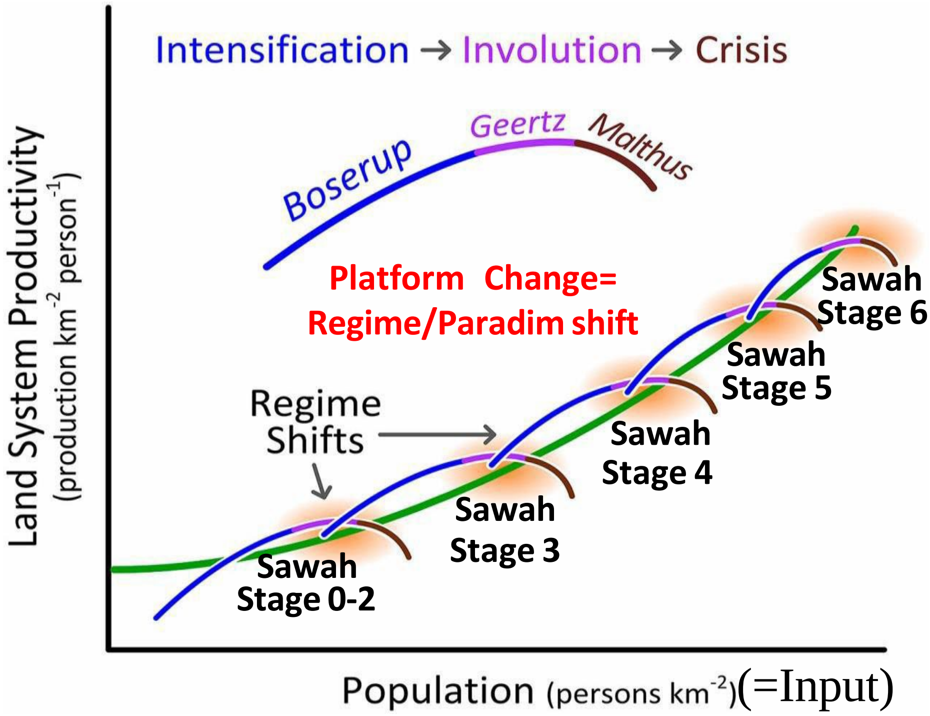


Figure. 22. General model of land-use intensification. Arcs depict individual land-use systems with three phases: intensification (Boserup; 1965), involution (Geertz; 1963), and crisis (Malthus; 1798), with regime shifts from less to more productive land systems. Green line highlights general trend toward increasing productivity with population (Ellis et al. 2013)

Figure 22 is a diagram quoted from Ellis et al. (2013), and the authors' hypothesis that the evolutionary stage of the rice-growing platform, that is sawah platform, is important as a major factor in the regime shift in rice productivity improvement. Ellis et al. exemplify the technology of using fire in shifting cultivation, wet rice cultivation (the technology is not specified), moldboard plow, synthetic nitrogen fertilizer and mechanization, as technical factors for regime shift of intensification.

Our hypothesis is that the level of evolution of platforms for farmland water control and soil erosion management forms the basic regime of rice farming systems. Namely, Sawah evolutional stage 0: Upland rice cultivation platform with no bunding, no leveling, and no human made water control and soil erosion control. Evolutional Stage 1: Lowland without bunding and leveling (irrigation or rainfed) and Stage 2: Lowlands under ridge cultivation (with or without bunding; as irrigated or rainfed). These two platforms have no human made water control and soil erosion control. Stage 3: Lowland under micro-rudimentary sawah platform (irrigated or rainfed), which can some water and soil erosion control. Until Stage 0-3, high-yield varieties, chemical fertilizers and pesticides, and irrigation and drainage technology cannot be used effectively. Evolutional stages 4 and 5 accommodate various green revolution technologies. Stage 4: Lowland irrigated standard sawah platform with one plot size larger than ca. 100 m^2; strong bund and the leveling degree of the soil surface within the same plot is less than ±5 cm for standard transplantation with animal plowing. Stage 5: The same to the stage 4 except for power tiller or tractor plowing. Farmers can control water and soil erosion. Evolutional stages 5 and 6 for mechanized farming: Stage 5: Lowland irrigated Sawah platform with plot size larger than ca.1000 m^2 and good bund and leveling quality is less than ±5cm. Power-tiller and/or small tractor cultivation. Stage 6:

Tractor-based advanced irrigated sawah platform with plot size is larger than ca. 1000 m^2. Good bunding, leveling quality is less than ± 2.5cm using lazar leveler. Separation of irrigation and drainage canals. Evolutional Stage 7: Possible future platform for easy water control including sawah dam function, sustainable productivity in intensive and biodiversity farming, and effective mitigation of global warming

9. Sawah Hypothesis 2: Lowland irrigated sawah system is an intensive sustainability platform. Its sustainable productivity is more than ten times that of upland rice farming, i.e., the sustainable productivity of 1 ha of irrigated lowland sawah system platform is more than 10 ha of upland field, i.e., yield difference (>2) x soil fertility resilience (>5). It is integrated with catchment forest and upland farming to form watershed agroforestry (Africa SATOYAMA system). This will also serve as a core platform for the agricultural sector to deal with global warming.

Table 3 and Figure 23 show that the rice cultivation deployed on the Sawah platform is more than twice the productivity of upland rice. These are the supporting data of Sawah hypothesis 2, which will be described below.

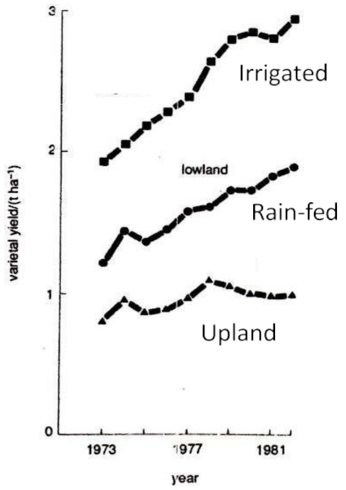


Fig.23 Yield trends for irrigated rainfed, and upland rice in the Philippines, (Evans 1986)

Table 3 National Mean Paddy Yields (t/ha) of Sawah and Upland Fields in Japan during 1970-2010

Year	Sawah	Upland
1970	6.8	2.8
1980	6.4	3.3
1990	7.9	3
2000	8.3	3.9
2010	8	3
1960	16.2	
(No.1 farmer)		

Milled rice:Paddy rate is 65%
(MAFF statistics in 2011/2012)

Table 4. Sawah hypothesis (2) : Sustainable productivity of standard sawah platform (Evolutional stage 4) is more than 10 times than upland field

1ha sawah is equivalent to 10-15ha of upland

	Upland	Lowland(Sawah)
Area (%)	95 %	5 %
Productivity (t/ha)	1-3 (1 ≦ **)	3-8 (2**)
Required area for sustainable1 ha cropping*	5 ha :	1 ha

* Assuming 2 years cultivation and 8 years fallow in sustainable upland cultivation, while no fallow in sawah
**In Case of No fertilization

The sustainable paddy yield in upland and non-sawah fields in Philippines and Africa is less than 1 ton per hectare, while standard sawah fields can get 2 tons even if no fertilized in Japan, Philippines and SSA (Figures 6,19, 20, 23). But if standard sawah fields are developed in lowlands and fertilized properly, paddy yield will be 3-8 t/ha, while the paddy yield in upland will be less than 1 and the maximum 3 t/ha even in Japan (Figure

23 and Table 3). The yield difference between UK wheat and Japanese paddy rice shown in Fig. 6, 19, and 20 before the establishment of modern agriculture until about 1700-1900 is also about twice as large.

It is necessary to restore the soil fertility by fallow in upland rice fields in most of the areas in SSA. As shown in Table 4, most of the upland rice by shifting slash-and-burn cultivation areas in SSA require a fallow period of eight years or more after approximately two years of upland rice cultivation. Namely, as shown in Table 4, it is necessary to secure extra 5 ha of farmland usually to sustain 1 ha upland rice cultivation. The possible sustainable yield of upland rice by shifting cultivation in West Africa is about lt/ha or less in paddy base and that of rice cultivation in lowland standard sawah fields, evolutional stage 4, is about 2.5t/ha without fertilization (Wakatsuki, 1991). In lowland rice growing in sawah platform, continued planting is possible due to the macroscale mechanisms in watershed level and the micro-scale ecotechnological mechanisms described in Figure 24, fallow is unnecessary and it is possible to cultivate continuously in units of 100-1000 years. Thus the ratio of sustainable productivity of sawah fields to upland fields can be calculated by multiplying (ratio of yield) by (ratio of continued planting). A simple calculation using the above figures ((2.5/1) X (10/2)) results in 12.5. This means that sawah platform fields have sustainable productivity 12.5 times as high as that of upland rice fields. The functions of sawah platform in the global environment and biodiversity conservation should be emphasized more and more in the future, especially in SSA. From a global perspective, sustainable sawah system development in Africa could save the earth society around the year 2050. It could be one of the strategies to realise the 2030 Agenda for SDGs (Sustainable Development Goals) adopted by the United Nations.

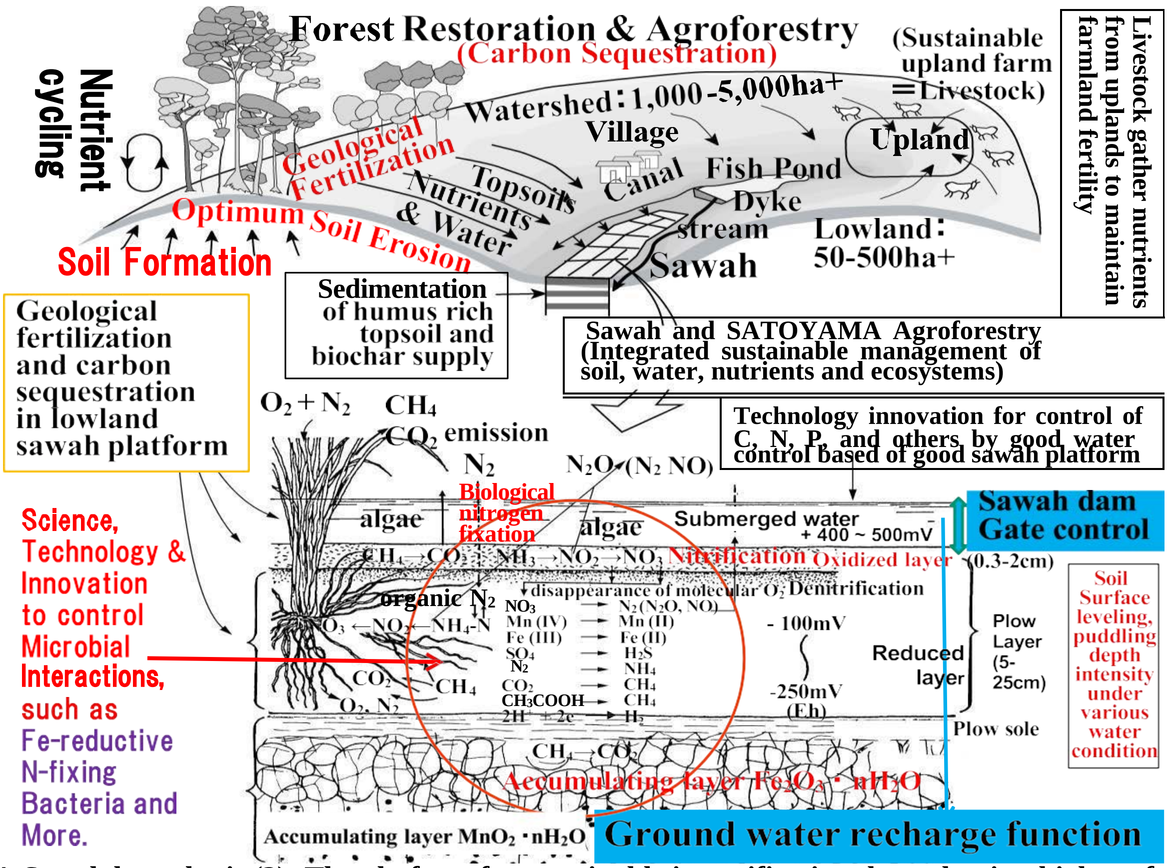


Fig.24. Sawah hypothesis (2): The platform for sustainable intensification through microbial eco-factory and watershed agroforestry (African SATOYAMA)

(Reason 1) Geological fertilization process is pedological foundation of intensive sustainability of sawah platform.

The upper part of Figure 24 illustrates the concept of watershed ecotechnology, or watershed agroforestry. This system is equivalent to Japanese term of SATOYAMA system (Wakatsuki 1997, Wakatsuki et al 2001b. Wakatsuki 2002, Wakatsuki and Masunaga 2005, Takeuchi 2010, Fukamachi et al 2001). The water cycling in the watershed weathers rocks, forms soils, erodes soils and forms colluvial soils for sawah platforms. It is important to control the balance between appropriate soil erosion and the formation of soil. Ideal land-use patterns and landscape management practices will optimize these geological fertilization processes by ensuring optimum hydrology in a given watershed. The nutrients released during rock weathering of and soil formation in the upland areas of the watershed are transported by the hydrological cycle to the lowlands, where they accumulate and eventually flow out through rivers to the sea. Irrigation, surface, and subsurface waters also increase the supply of nutrients such as Si, Ca, Mg, K, and S. These processes provide the ecological engineering basis for the sustainability of intensive lowland *sawah*-based rice farming (Greenland 1997, Wakatsuki et al. 1998, Hirose and Wakatsuki 2002, Ofori et al. 2005, Wakatsuki and Masunaga 2005).

The yearly volume of rock weathering and soil formation is a basic condition for allowing plants to take up nutrients and keep their primary productivity. The reported values of the rates of rock weathering and soils formation for the tropics have wide range of 0.1-l00t/ha/y (Buol et al.,1989). It is considered that the figure is large in fertile volcanic ash soil and low in aged soils of Oxisols zone, but reliable measured values are very few at present, because of methodological difficulty. More recently, the earth's average soil formation rate was estimated at about 0.7t/ha/y and the rate of rock weathering at 0.8t/ha/y (Wakatsuki and Rasyidin., 1992, Wakatsuki et al 1993). If soil erosion is smaller than soil genesis, Oxisols will ultimately be formed, while if soil erosion grows excessive, the soil will be degraded. The global average soil erosion rate is estimated at 0.9t/ha/y (World Resource Institute, 1990). The areas with less soil erosion are observed in the Congo basin and the Amazon lowlands where the senile soil of Oxisol is distributed. By contrast, soil erosion is very high in the volcanic zones and in the basins of large Asian rivers where geological fertilization is active and so is soil genesis. Since these areas are densely populated, they may also be regarded as the regions where there is most human induced soil degradation. However, when considered from the perspective of biological metabolism, these areas have a relatively high rate of soil erosion, but this is due to the fact that the rate of soil formation is the most active in the world, and therefore fertile soils are formed on the balance between soil erosion and soil formation. True, soil erosion is the most important factor of soil degradation but it has another aspect, that is, the function of soil metabolism, renewal, and restoration, too. Neither the formation of lowland soil nor of sawah field soil is possible without soil erosion. The reassessment of soil erosion from this standpoint will become an important research subject in the future.

If a sawah system is developed in the lowlands, it is possible to store and use effectively this nutrient-rich water and fertile topsoil. This is the basis of the ecological environment for the long-term sustainability of high productivity in sawah systems for several hundred to one thousand years or more. However, while relatively large amounts of data exist on the importance of irrigation water, there is little quantitative data on the movement, deposition and run-off of soils that move with the water and are deposited in low-lying areas.Because of this, a great deal of supposition is needed for discussions on this subject at present. This is the field that should be given high priority in future studies for the evaluation of the ecological sustainability of a watershed. Let's suppose lt/ha/y is the soil formation rate in the uplands which account for 95% of the total area in the case of the watershed shown in Figure 24. Since the soil genesis and erosion rates should be evenly balanced in a stable watershed ecosystem, the topsoil formed in the upland (95% of the area) and the nutrients discharged in this pedogenic process are concentrated in the lowlands (5% of the area). Therefore, the soil formation rate in the lowlands is equivalent to 20t/ha/y. Though all of them cannot be used in lowland sawah fields, sawah systems will still be the best platform to make effective use of the fertile soil and nutrient-rich water from the uplands. In short, the sawah system in lowlands is the one capable of using effectively the benefits produced by the huge stock of uplands. As seen from Figure 24, if it is combined with lowland sawah systems, forest ecosystems where trees send out roots deep into the ground and help to form topsoil further reinforce the topsoil formation, water holding function, and sustainable productivity of the whole watershed. The combination like this of forests and lowland sawah systems in the watershed is a kind of traditional agroforestry that has attracted attention recently. We may name this watershed agroforestry. It is an excellent platform for sustainable production that Japanese and Asian traditional sawah based agricultures have developed. It is a restoration technology for the degraded environment of watershed, by the combination of forests and sawah systems. The purpose of this study is to consider ways to restore degraded lowlands and uplands in West Africa and SSA by the use of this environmental technology and platform.

Let us suppose that the average soil formation rate in the watersheds in Japan is about 3t/ha/y (the rate is estimated at about lt/ha/y in granite areas, 5t/ha/y in basic volcanic rock areas; Wakatsuki et al., 1993). Soil formation and erosion are balanced with each other in a mature ecosystem. In Japan, lowlands have been well developed and the topsoil formed in uplands (about 85% of the area) and the nutrient-rich water released in the pedogenic process are supplied to lowlands (15% of the area). Thus the rate of soil formation in lowlands is 5.7 times as high as the average, that is, 17t/ha/y. Supposing the bulk density of lowland soil to be 1.0 g/ cc and the sedimentation rate to be 50%, the annual average rate of soil formation (sedimentation) is 0.9mm, which means that 90cm of lowland soil is sedimented (renewed) in 1,000 years.

The photographs in Figure 25 below show micro (rudimentaly) sawah plots (evolutinal stage 3) developed about 2500 years ago. Those were discovered during archaeological sites excavation. These 2,500-year-old micro sawah plots are covered by various alluvial soil deposits 3-5 m thick below the present topographical surface. As shown in Figure 25, many results of excavations and soil profile surveys on various old archaeological sawah remains from the Yayoi and Kofun era, about 3000-1700 years ago (Takaya and Kuraku1988, Archaeological Institute of Kashihara 2019, and Okada and Kanehara 2022) shows that the sedimentation rate of lowland soil on sawah fields was 70-200cm/1,000 years. This supports the estimated figure for a 1,000-year period mentioned above.

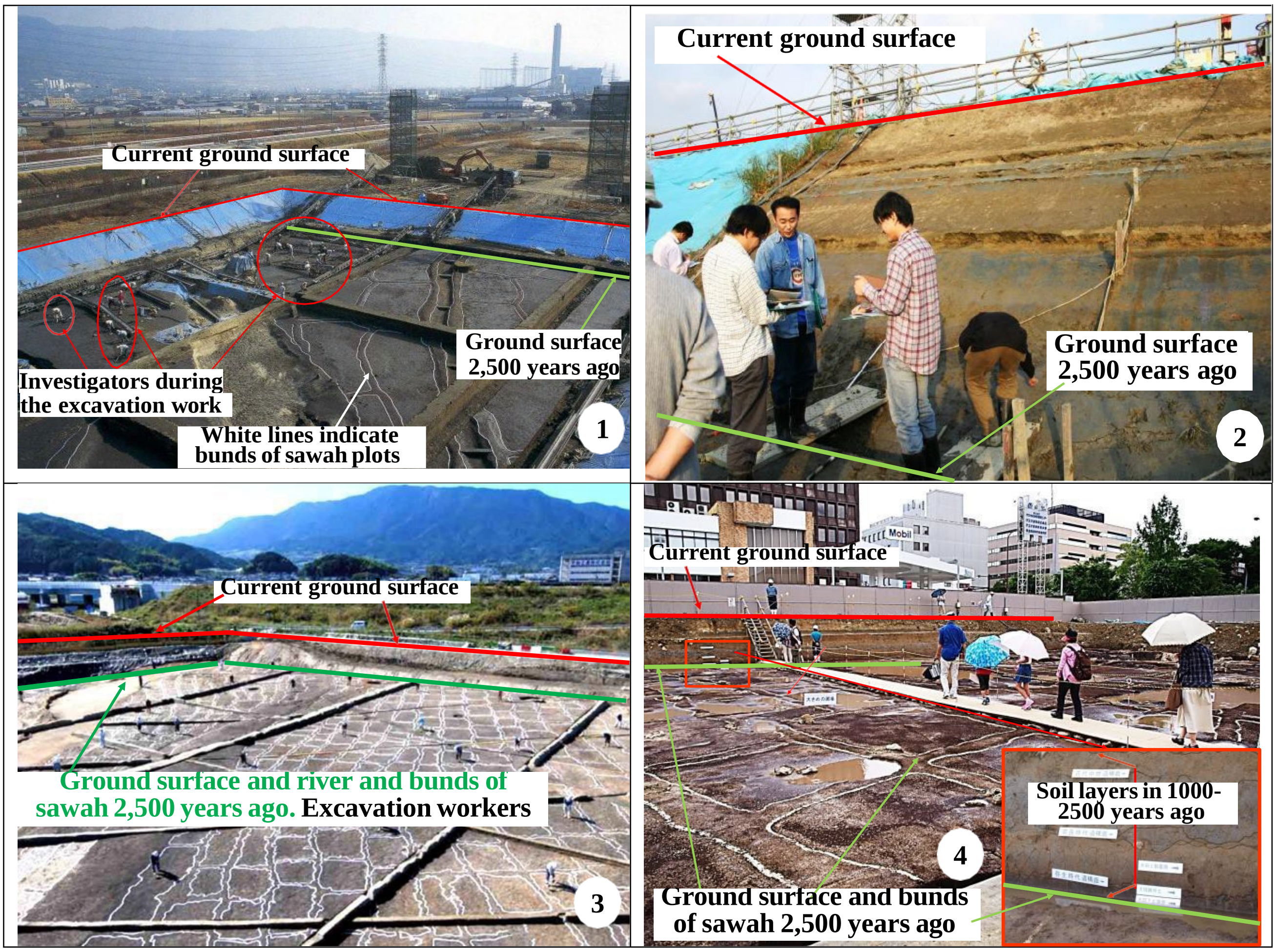


Fig.25: ① and ② are Fukumanji/Ikeshima archaeological excavation site, Osaka Prefecture, which photos were taken in March 2008 (34.649N 136.625E). ③ is the Nakanishi archaeological excavation site in Nara Prefecture (34.447N 135.742E) Photo is cited from Archaeological Institute of Kashihara (2019), . ④ is an archaeological excavation site 200m south of City hall (34.6836N 135.805E) in Nara City. White lines indicate ridges of weir-irrigated subdivision sawah (paddy) plots with sizes of 10-30m^2. The radioisotope age of the woods used for the weirs of these irrigated sawah (paddy) plots were 2500-2400 years ago (Okada and Kanehara 2022).

The upland farming sustainability model is illustrated to the right of a watershed model in the upper half of Figure 24. This model shows, another method for realizing the intensive sustainability of upland farming is the combination of agriculture and stock raising. In this case, animals (cattle, pig, chicken) play the role in accumulating nutrients. This method involves the application of various livestock manures to the agricultural fields to conserve soil fertility. But unlike water, it is impossible to raise very much the efficiency of the accumulation of the nutrients absorbed by grassland vegetation-in uplands. It is also more likely to lead to deforestation in the watershed, as it requires larger areas of crop field and grassland than forests. Thus this system is apt to result in the destruction of the watershed environment. Stock raising can also be combined with lowland sawah platform. In this respect, too, it is evident that sawah systems are advantageous.

(Reason 2) Sawah system is an ecological factory, it can artificially strengthen and control nutrients such as N, P, K, Si, and micronutients through water control and redox control. It is also the platform to control various redox microorganisms to control carbon sequestration and metane as well as nitrous oxide emmission.

Yanai et al. (2020, 2021, 2022a, 2022b), Tanaka et al. (2021, 2022), Abe et al(2022), Darmawan et al. (2006, 2022), and Nakao et al. (2021, 2022) compared changes topsoil fertility in the same panel sawah (paddy) fields a total of 225 sites in Southeast Asian countries between the 1960s (Kawaguchi and Kyuma 1977) and the 2010s of the Green Revolution period. Panel sites are 65 points in Thailand, 40 points in Java Island in Indonesia, 43 points in Bangladesh, 37 points in the Philippines, and 40 points in Malaysia. They reveald that (1) P fertility was remarkable improved in all the countries, (2) Excangeable K and available N were persistent over 50 years, (3) Soil organic matter was increased in many cases, except for originally Histosols areas, suggesting the potential of the sawah platform to contribute to carbon sequestration in tropical Asia and Africa.

The lower half of Figure 24 shows the micro-scale mechanisms of the sustainability of the *sawah* system. The *sawah* system can be managed as a multifunctional constructed wetland1 platform. Submerged water can efficiently control weeds. Under submerged conditions, P availability is increased through the reduction of ferric iron. Both acid and alkaline soil pH are neutralized or mitigated by appropriate regulation of submergence. Hence, micronutrient availability is also increased. These mechanisms encourage the growth of rice plants and various aquatic algae and other aerobic and anaerobic microbes, which increase N fixation in the *sawah* systems through increases in photosynthesis, hence the status of the *sawah* systems as functional wetlands. Appropriate puddling is not only effective in controlling weed germination, but is also important for making the sawah soil muddy and soft, and for facilitating through various nanowire interactions the cooperative action of the diverse microbial consortia united (Kyuma 2004, Nielsen et al 2010).
Recently other direct microbe interaction on anaerobic oxidation in the consortia of methane-oxidizing archaea and sulphate-reducing bacteria common environment in Sawah soil (McGlynn et al. 2015). Masuda et al. (2017), Xu et al. (2019) and Senoo et al. (2020) found that various reductive nitrogen transformation processes such as nitrate denitrification, ammonia production and nitrogen fixation are underway in anaerobic soil layers in sawah soils under waterlogging. Science and technology on the interaction between waterlogged/non-flooded and microbial consortia is still under development in sawah (paddy) soils. Some advanced organic sawah (paddy) rice farmers have developed a new technology to control weeds without the use of herbicides, which involves sawah plot levelling within ±2.5 cm, shallow (about 5 cm) and careful soil surface puddling and shallow flooding (Matsushita 2013). This innovative technology must be scientifically studied and improved.

Table 5. Comparison of the quality and quantity of weeds under direct-sown upland rice conditions (soil moisture content 30-60%), submerged water (6 cm water depth) cultivation after transplantation and direct-sown moist conditions (soil moisture content 80-90%). Comparison of biomass per unit area of C-3 weeds and C-4 weeds during the maximum tillering stage of rice

		Weed (g/m^2)		
	Soil moisture	Total	C-3	C-4
Upland	30-60%	58	6	52
Moist	80-90%	31	3	28
Sawah	flooding (6 cm depth)	10	9	1

Tanaka I (1976) compiled C-3 and C-4 weeds
based on original data by Arai et al (1955)

Table 5 shows why weed control, which is responsible for the greatest low-yield of agriculture in the humid tropics, is easier when transplanted on a standard sawah platform at evolutionary stage 4 compared to any other farming systems. there is This is the reason why most rice farmers can achieve a paddy yield of 4t/ha or more without any special special skills in rice cultivation.

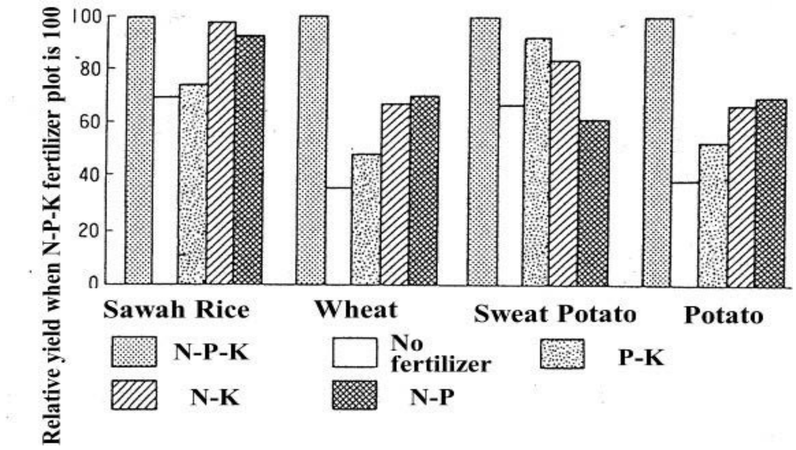
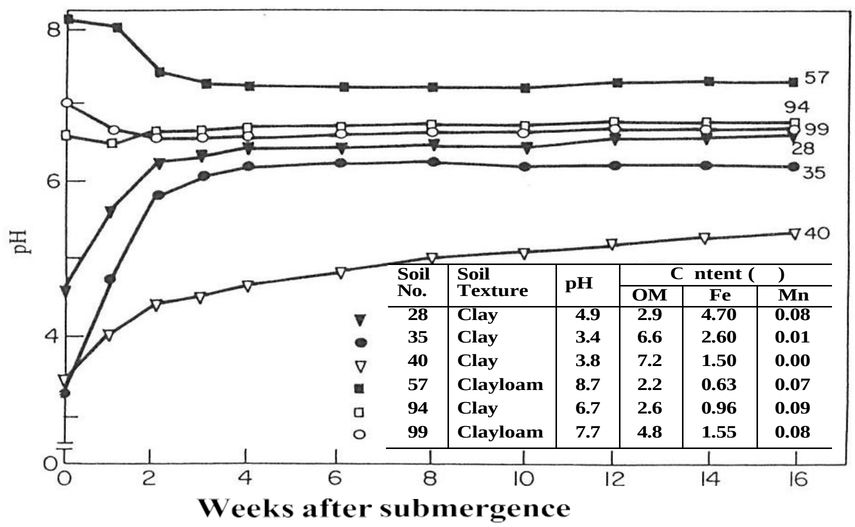


Figure 26. Three years continuous fields experiment in all 47 states in Japan (Tanaka M, 1976) of Sawah based Rice, Upland based Wheat, Sweat Potato and Potato

Figure 26 demonstrates that the irrigated sawah platform has a higher natural ability to supply N, P, and K than the wheat upland field platform. In the case of no N-P-K fertilization, the wheat yield decreased by 70% compared to the control NPK standard fertilization plot, but the yield decreased by only 30% on the irrigated sawah platform. This is because various nitrogen-fixing microorganisms use carbohydrates such as algae and rice plants to fix nitrogen under the optimum flooded conditions shown in the lower part of Figure 24. Irrigated sawah platforms in tropical climates can fix 20-200 kg of nitrogen per hectare per year, depending on management techniques and soil/climatic conditions (Greenland 1997, Kyuma 2004). This amount is comparable to the amount of nitrogen fixed by leguminous plants in upland farming. Sweet potato is also known that various nitrogen-fixing bacteria coexist in the stem. The amount of N fixation can change through the control of N fixing microbes, availability of P and Fe, which are influences by water management and redox. Phosphoric acid fixed by iron oxide which is not available to plants is converted to a soluble available form, which can be absorbed by plants, under reducing conditions due to waterlogging. K is supplied by irrigation water in addition to available K in soil. Although not shown in Figure 26, Si can be also supplied from irrigation water. Upland platform where wheat and potatoes are grown do not function as ecological factories like the irrigated sawah platforms described above. Various new science, technology and innovative research can be done under sawah platform as shown in Figure 24.



	Soil No.	Soil Texture	pH	C ntent ( ) OM	Fe	Mn
▼	28	Clay	4.9	2.9	4.70	0.08
●	35	Clay	3.4	6.6	2.60	0.01
▽	40	Clay	3.8	7.2	1.50	0.00
■	57	Clayloam	8.7	2.2	0.63	0.07
□	94	Clay	6.7	2.6	0.96	0.09
○	99	Clayloam	7.7	4.8	1.55	0.08

Fig. 27. Sawah soil neutralization through submergence (Ponnamperuma 1984)

Figure 27 shows how the length of the submergence (week) affects soil pH change in the sawah platform with different soils of different texture, organic matter (OM), Fe and Mn contents (Ponnamperuma 1984). After about two weeks of flooding, the oxidation-reduction potential of soils decreased, and the initial pH of the alkaline soils, which had initial pH of 8.2-7 before flooding, dropped to pH 6.5-7.2, while the pH of the strongly acidic soils, which had pH of 3.5-4.6, rose to around 4.5-6.2. Flooding of the sawah platform has the effect of promoting the absorption of trace elements necessary for rice growth and reducing the availability of toxic metals, Flooding of the sawah platform has the effect of promoting the absorption of trace nutrients necessary for rice growth, but increase methene emission.

(Reason 3): Comparative evaluation of global warming potential between upland crops farming (Ug_{wp}) and irrigated lowland sawah platform for rice farming (Sg_{wp}): Note on conversion factors, $3.66C=CO_2$, Global warming coefficient, i.e., $CO_2 : CH_4 : N_2O$ = 1: 28 : 265 (IPCC 5th report 2014)

(1) Carbon sequestration under watershed agroforestry, or Satoyama system:

(1)-A, Example of Integrated watershed agroforestry (Africa SATOYAMA System): Forest-Cocoa plantation-Fish pond- Sawah system: An Adugyama Model, Kumasi, Ghana

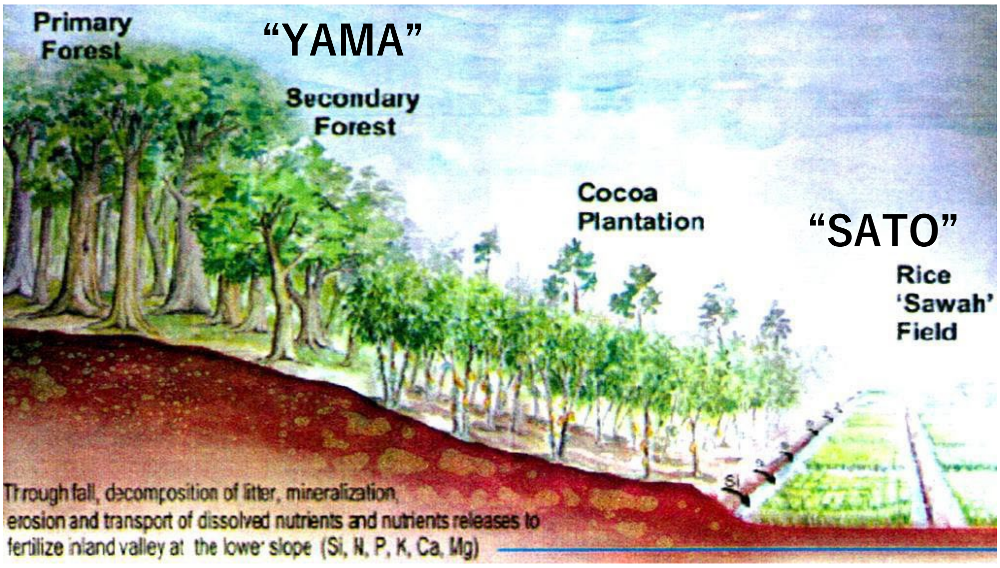


Fig. 28. One Example of Africa SATO-YAMA Concept by Dr. Owusu, FoRIG, Ghana, an extending cocoa agroforestry into sawah platform in a watershed applicable to Cocoa belt region in West Africa.

As shown in Fig. 28 of concept figure lowland sawah systems can integrate with various upland tree based systems. As shown in four photos of Figure 29 below, cocoa plantation in lower slope of watershed is particularly promising in a watershed of forest transitional zone in Ghana. Citrus plantation is also good combination of land use.

Kumasi, Gold valley Site, Non Sawah and Cacao farm, Aug. 1999, (6.887N 1.888W)	**Mt, Oscar's Sawah rice and Cacao farm, at Afari, Kumasi, Ghana, (GPS position: 6.6885N 1.7856W)**
	

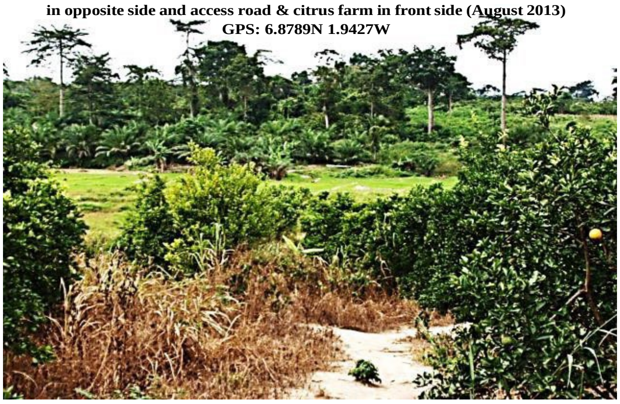


Fig. 29: Photos showing examples of Africa watershed agroforestry. Lowland sawah with upland Cacao farm, and Citrus farm, Mankranso area, Kumasi, Ghana

(1)-B: Carbon sequestration through forest conservation by sawah platform; 1 ha of upland cultivation requires the destruction of at least 1 ha of forest or 1 ha of grassland. For sustainable agriculture, upland cultivation requires additional fallow land and livestock holding areas of 10-15ha (Fig. 24). On the other hand, 1 ha of lowland irrigated sawah rice cultivation can conserve 10-15 ha of forest (see Table 4). In other words, if the carbon fixation of 1 ha of forest (Sgcwsa) is 1500 kgCO_2/ha/year (the national average in Japan), 37 million tons of CO_2 can be fixed annually in Japan's forest area of 24.8 million ha (Ministry of Agriculture, Forestry and Fisheries, 2022).

(1)-C: Carbon sequestration through geological fertilization process in lowland sawah platform by sedimentation of eroded upland soil.

The average rate of soil formation of the earth is about 1 Mg/ha/yr and the soil erosion rate in upland farms is more than 10 Mg/ha/yr (Wakatsuki and Azwar 1992, Wakatsuki et al 1993, Lal and Stewart 1992). The average organic carbon lost in this erosion is estimated to be 0.12 Mg/ha/yr (0.44 MgCO_2/ha/yr) in med western USA (Kwang et al 2023, Van Oost and Six 2023). In Asia, this eroded topsoil can be deposited in lowland alluvial areas, and the presence of sawah platforms increases its collection effect. As shown in Figure 25, in Japan, 2500 years of continuous lowland sawah rice cultivation in Japan has resulted in the formation of a sedimentary soil stratigraphy with a thickness of about 3-5 m. In the case of upland soils in tropical and temperate regions, organic matter accumulates generally in shallower than 30 cm and the upper limit of accumulated organic matter is less than 100 Mg/ha, even if soil depths of up to 100 cm are taken into account. In the alluvial lowlands, however, the average is above 100 Mg/ha. In the example of ② in Fig. 25, the total organic carbon content up to a depth of 5 m is estimated to be higher than 300 Mg/ha and the carbon sequestration rate is estimated at higher than 439 kgCO2/ha/year.

(2) Carbon sequestration potential of irrigated sawah platform for rice cultivation in comparison with upland farming systems: Carbon sequestration rates of upland soils have lower than and carbon emission rates of upland soils have higher than those of irrigated sawah platform (Fig. 30-32 and Table 6) either farm yard application (FYM) or not.

(2)-A: Carbon sequestration increases significantly when alluvial lowlands are used for irrigated sawah rice cultivation compared to when they are used for upland crops cultivation (Figs. 30 and 31 and Table 6 for Japan and China)**.**

Figure 30 below shows an example of a long-term trial of irrigated sawah and upland field conversion in Japan. The results demonstrate the importance of irrigated sawah platforms in carbon sequestration, which should be promoted in SSA in the future. The carbon accumulation effect of rice straw compost application for 12 years from 1970-1982 is shown in Ⓐ. The carbon content of topsoil(0-16cm) layer increased by 27-20.2=6.8gC/kg (33.6% in 12 years, 2.8%/year). The average annual increase over 30 years was 1.9%/year. It is noteworthy that the carbon content of the topsoil layer was maintained even in Ⓑ, where no rice straw compost was applied. Of particular note is the comparison of the 18-year continuous irrigated sawah rice cultivation from 1982-2000 and the 18-year continuous soybean cultivation by converting the irrigated sawah fields to the upland field using the same soils. This is the result of an 18-year long-term study comparing the effects of rice straw compost application between irrigated sawah rice cultivation and upland soybean cultivation as shown ①-④ in Figure 30.

During this 18-year period, the carbon content of the topsoil increased by 15.9% (0.88%/year) to 27-31.3=-4.3 g/kg in the ①plot of irrigated sawah rice with straw compost. On the other hand, in the ②plot, soybeans were cultivated after converting to upland field, the carbon content of the topsoil decreased by 12.2% (0.68%/year) to 27-23.7=3.3 g/kg, despite the application of the same amount of rice straw. In total, the difference in carbon sequestration between the rice straw compost-applied plot in the ① irrigated sawah rice field and the ② upland soybean field was 31.3-23.5=7.8 g/kg, a 28.9% (1.61% annual rate). Similar differences were observed in the ③ irrigated sawah rice cultivation without rice straw compost application and the ④ upland field-converted soybean cultivation. The carbon content increased by 14% (0.78%/year) to 22.8-20=-2.8 g/kg in the ③irrigated sawah rice field, but decreased by 15% (0.83%/year) to 17-20=-3 g/kg in the ④upland field-converted soybean field, despite no application of rice straw compost over 18 years. The difference in carbon sequestration between ③irrigated sawah rice and ④upland field-converted soybean was 22.8-17=-5.8 g/kg over 18 years, a 29% increase (1.6%/year).

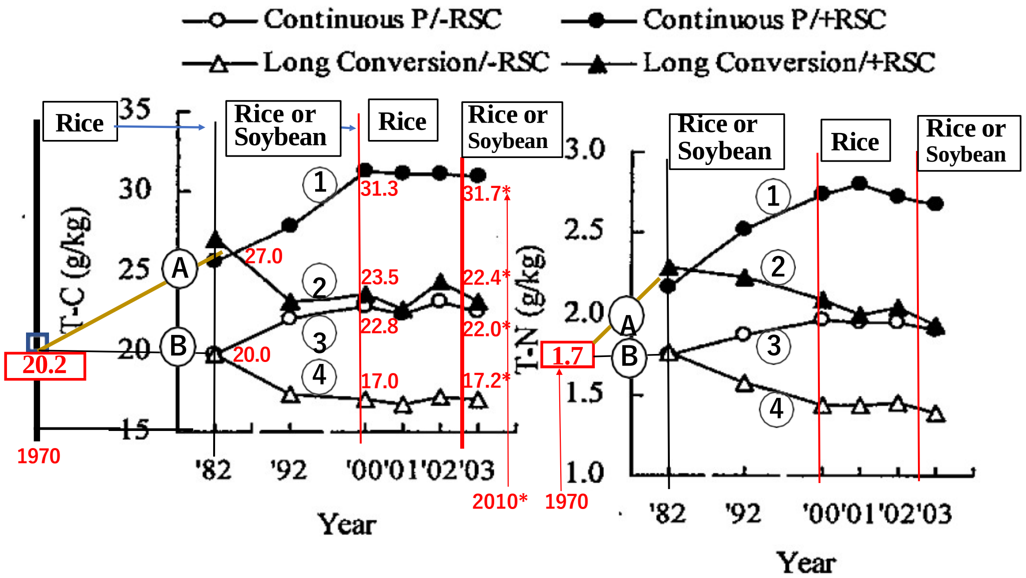


Fig. 30. Changes in the total carbon and total nitrogen (g/kg) contents of the topsoil (0-13 cm) of irrigated sawah rice and its converted upland soyabean rotation with rice straw compost 20 t/ha (+RSC) and without rice straw compost (-RSC) in 1970-2003 (and until 2010). This long-term experiment was conducted at Daisen Research Station, Tohoku Agricultural Experiment Station, Japan. P, Paddy (Sawah); RSC, Rice, Straw Compost. Before 1970 the experimental site was used for irrigated sawah rice cultivation.

In 1970, the site was divided into two plots, Ⓐ irrigated sawah rice cultivation with rice straw compost 20 t/ha (+RSC) (brown line) and Ⓑ with 0 t/ha (-RSC) (black line).

In 1982-199, these two plots were further divided into two plots respectively, i.e., ① continuous irrigated sawah rice with 20t/ha (+RSC), ② converted to upland soybean with 20t/ha (+RSC), ③ continuous irrigated rice with 0 t/ha (-RSC) and ④ converted to upland soybean with o t/ha (-RSC). (Cited from Sumida et al 2005, Takakai et al 2020, Shirato et al 2011, Nishida 2022).

Note: In 2010-2011, the final year of the 1970-2011 long-term trial (Figure 30), paddy yield was 9.6-10.1 t/ha (conversion rate of brown rice/paddy rice = 0.65) in the 20 t/ha rice straw compost application and standard fertilizer application (N-P_2O_5-K_2O: 100-70-70) and 8.2-8.2 t/ha in the no rice straw compost application and standard fertilizer application. The amount of rice straw compost applied at 20 t/ha is equivalent to about twice the amount of rice body residue from one crop.

.

The left side of Figure 31 below shows the organic carbon distributions in paired soil profiles of adjacent irrigated sawah rice farm and upland crops farm in the same Brown lowland soil series on the natural levees of the Tsukigawa River (Ogawa-cho, Saitama Prefecture, Each of the land use has been in place for more than 53 years) and the Kinugawa River (Sekijyo-cho, Ibaraki Prefecture, Each of the land use has been in place for more than 35 years) flood plains. On the right are similar paired organic carbon profiles of adjacent irrigated sawah and upland crops farms of Gray Lowland soils on Bank swamps in the Tadotsu-cho, Kagawa Prefecture and in the Higashi-Chichibu-Cho, the Tsuki River, Saitama Prefecture. Each of the land use has been in place for more than 100 years (Mitsuchi, 1974a, 1974b). Numerical data for these figures are shown in Table 6.

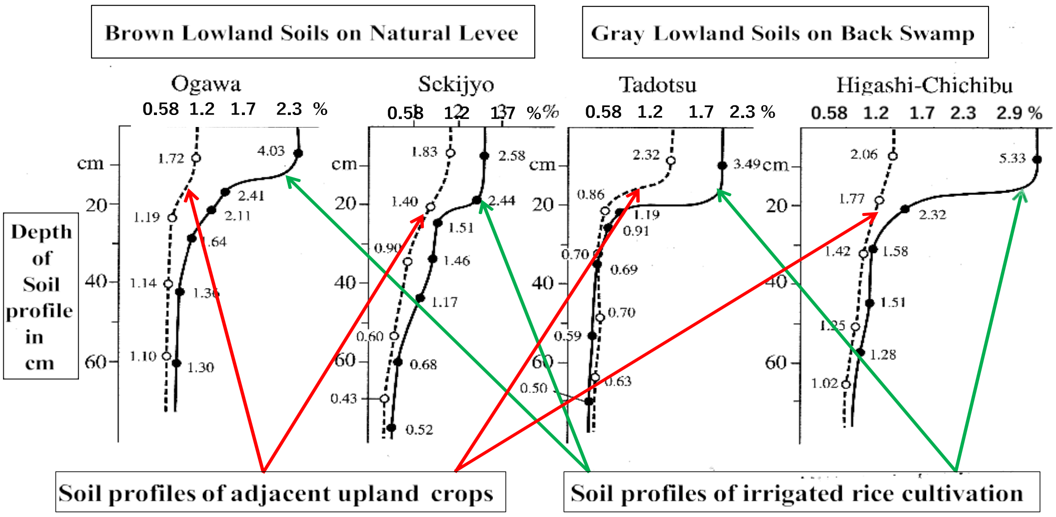


Fig. 31. Comparison of organic carbon % in the two adjacent same soil series originally but different cultivation of irrigated sawah rice or upland crops cultivation on the same topographical position (Carbon % are calculated by 0.58xTotal humus %, of which source is Mitsuchi 1974)

(2)-B: Green revolution technology can intensify the function of soil carbon sequestration (Table 6, Java, Indonesia, Bangladesh, and Thailand)

(2)-C: Newly developed or converted upland crop soils are always emission source of carbon dioxide by rapid decomposition of humus of original sawah, forest or grass land soils (Fig.30 and 31, Table 6).

(2)-D: No carbon sequestration (net emission) except for heavy application of farm yard manure (more than 20-35ton FYM/ha/y) to the upland crop soils. Organic carbon accumulates significantly in upland soils only when their organic carbon content has been reduced to less than 30-50% of the initial organic carbon level of the virgin site (① Hoosfield site of Rothamsted of Fig. 32. Numerical data of the ① are shown in Table 6).

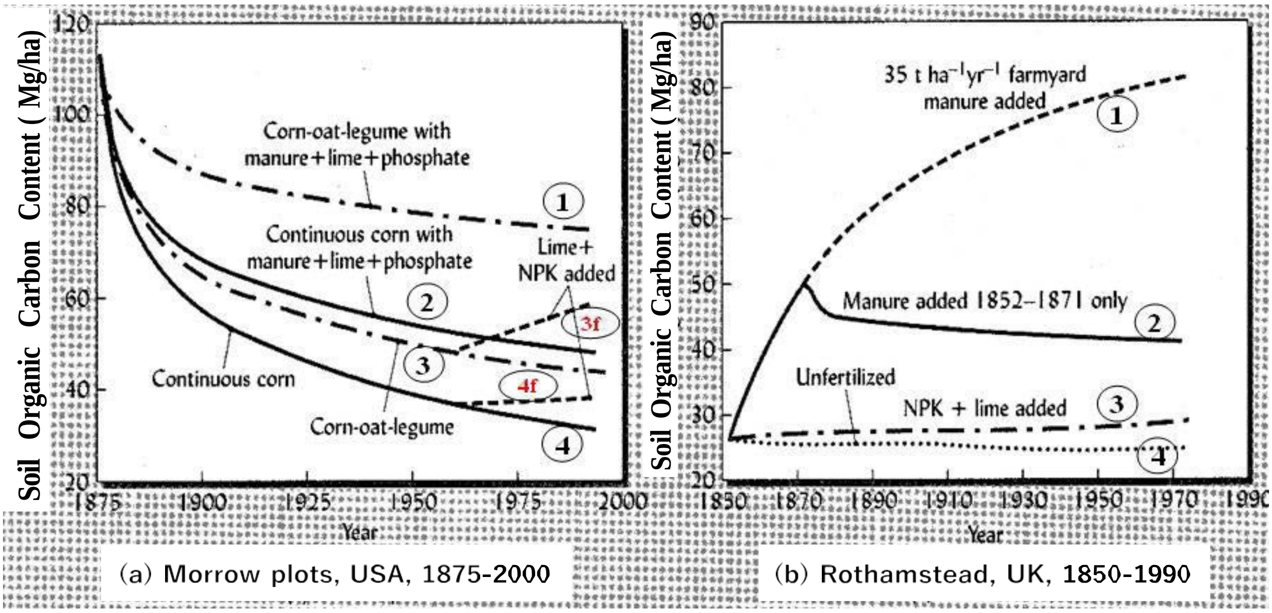


Fig.32. Soil organic carbon contents of selected treatments of (a) the Morrow plots at the University of Illinois, USA and (b) of the classical experiments at Rothamsted experiment station in England. The Morrow plots were begun on virgin grassland soil in 1876. The Rothamsted plots were established on soils with a long history of pre-vious cultivation. Forested original soil carbon stock in Rothamsted area was estimated to be 80-150 Mg/ha (Falloon et al, 1998).[Data recalculated from Darmody and Peck (1997) and Jenkinson and Johnson (1977) (Cited from Brady and Weil 2014)

Table 6. Long-term comparative experiments and international surveys on carbon sequestration or emission of sawah (paddy) and upland soils

Experiment or survey (Data sources)	Irrigated Sawah (Paddy) rice or Upland Crops	Treatment	Sampling period	Experi-ment years	Ammount of Organic C in measured depth: Depth	At start (Mg/ha)	At end (Mg/ha)	Diffe-rence (Mg/ha	Rate of increase(Mg C /ha/yr)	Annual increase (0/000/yr)
Japan (Fig. 30)		No rice strow compost	1968-2010	42years	0-16cm	33.5	37.1	3.6	0.086	2.6
Tohoku Agric Station	Sawah Rice, B(3) line in Fig.30	(Control)	1968-2010	42years	16-30cm	19.8	24.7	4.9	0.12	6.1
Grey lowland soil			1968-2010	42years	0-30cm	53.3	61.8	8.5	0.2	3.8
Typic Fluvaquent	Sawah Rice, A(1) line in Fig.30	Rice strow compost 20Mg/ha	1968-2010	42years	0-17cm	35.6	45.2	9.6	0.23	6.5
(Takakai et al, 2019)			1968-2010	42years	17-33cm	22.6	36.7	14.1	0.34	15
(39.494N 140.496E)			1968-2010	42years	0-33cm	58.2	81.9	23.7	0.56	9.6
	Sawah Rice (not shown in Fig.30, but the	Livestock manure compost 20Mg/ha	1968-2010	42years	0-18cm	37.7	57.7	20	0.48	12.7
	same experiment except for Livestock		1968-2010	42years	18-34cm	22.4	31.4	9	0.21	9.4
	manure compost)		1968-2010	42years	0-34cm	60.1	89.1	29	0.69	11.5
	Sawah Rice (B(3) line in Fig.30)	No rice strow compost(Control-sawah)	1982-2000	18years	0-13cm	27.2	30.1	2.9	0.16	5.9
	Converted upland soybean(B(4) in Fig.28)	No rice strow compost(Control-upland)	1982-2000	18years	0-13cm	27.2	23.1	-4.1	-0.23	-8.5
	Sawah Rice (A(1) line in Fig.30	Rice strow compost 20Mg/ha	1982-2000	18years	0-13cm	36.7	42.5	5.8	0.32	8.9
	Converted upland soybean(A(2) in Fig.30)	Rice strow compost	1982-2000	18years	0-13cm	36.7	31.9	-4.8	-0.27	-7.4
Japan (Fig. 31)	Ogawa irrigated sawah rice profile	Sawah rice cultivation before 1910	1963	>53 years	0-23cm	33.4	51	17.6	0.333	9.9
Brown lowland soils	**(Note 1)**			>53 years	0-100cm	89.3	122.4	33.1	0.625	7.0
(Natural Levee)	Ogawa upland soil profile control	Sawah soil was in the same soil series	1963	>53 years	0-16cm	33.4	15.7	-17.6	-0.333	-9.9
(Mitsuchi 1974)	**(Note 1)**	as Ogawa upland soil before the sawah		>53 years	0-100cm	89.3	56.2	-33.1	-0.625	-7.0
	Sekijyo irrigated sawah rice soil profile	Sawah rice cultivation started in1927	1963	35years	0-22cm	36.3	40.9	4.6	0.13	3.6
	(Note 1)			35years	0-100cm	75.0	89.8	14.8	0.42	5.6
	Sekijyo upland soil profile control	Sawah soil was in the same soil series	1963	35years	0-28cm	36.3	31.7	-4.6	-0.13	-3.6
	(Note 1)	as Sekijyo upland soil before the sawah		35years	0-100cm	75.0	60.2	-14.8	-0.42	-5.6
Japan(Fig. 31)	Tadotsu irrigated sawah rice soil profile	>100years of irrigated rice history	1963-1973	>100years	0-28cm	42.7	52.4	10.0	0.1	2.3
Grey lowland soils	**(Note 1)**			>100years	0-100cm	76.9	82.5	5.6	0.056	0.73
(Backswamp area)	Tadotsu upland soil profile	Sawah soil was in the same soil series	1963-1973	>100years	0-26cm	42.7	33	-9.7	-0.097	-2.3
(Mitsuchi 1974)	**(Note 1)**	as Tadotsu upland soil before the sawah		>100years	0-100cm	76.9	71.2	-5.7	-0.057	-0.74
	Higashic Chichibu irrigated sawah profile	>100years of irrigated rice history	1963-1973	>100years	0-25cm	55.1	77.6	22.5	0.225	4.1
	(Note 1)		1963-1973	>100years	0-100cm	129.8	153.1	23.3	0.233	1.8
	Higashi Chichibu upland soil profile	Sawah was in the same soil as Higashi	1963-1973	>100years	0-23cm	55.1	32.6	-22.5	-0.225	-4.1
	(Note 1)	Chichibu upland soil before the sawah		>100years	0-100cm	129.8	106.4	-23.4	-0.234	-1.8

Note 1. We (including China team in 2021) had not studied the organic carbon in the flood plain soils before irrigated sawah rice cultivation or upland crops cultivation started, which are several tens to more than 100 years ago. Using the patterns of increase of organic carbon in sawah soils and decrease in upland crops cultivation as shown in Figures 30 and 31, we estimated the increase and decrease in organic carbon as follows. As a first approximation, we estimated the increase and decrease in organic carbon from original floodplain soils at the beginning of the hypothetical survey by using the average of organic carbon in sawah (rice paddy) plot and organic carbon in upland plot at the time of the survey as the present amount of organic carbon in original floodplain soils at the beginning of the hypothetical survey.

Experiment or survey (Data sources)	Irrigated Sawah (Paddy) rice or Upland Crops	Treatment	Sampling period	Experi-ment years	Ammount of Organic C in measured depth: Depth	At start (Mg/ha)	At end (Mg/ha)	Diffe-rence (Mg/ha	Rate of increase(Mg C /ha/yr)	Annual increase (0/000/yr)
China	Sawah rice soils, single rice	Mid temperate climate	2016/2017	>30years	0-15cm	24.4	27.7	3.3	0.11	4.5
(Chen et al 2021)	Comparative upland soils, one season crop	Mid temperate climate	2016/2017	>30years	0-15cm	24.4	21	-3.4	-0.11	-4.5
10 counties per 4	Sawah rice soils, single rice	Warm temperate climate	2016/2017	>30years	0-15cm	13.9	14.1	0.2	0.007	0.48
climates, 6 paired	Comparative upland soils, one or two crop	Warm temperate climate	2016/2017	>30years	0-15cm	13.9	13.7	-0.2	-0.007	-0.48
adjacent sawah	Sawah rice soils, single or double rice	Subtropics	2016/2017	>30years	0-15cm	20.2	27.3	7.1	0.237	11.7
and upland soils.	Comparative upland soils, double crops	Subtropics	2016/2017	>30years	0-15cm	20.2	13	-7.2	-0.24	-11.9
Total soils collected	Sawah rice soils, single rice	Tropics	2016/2017	>30years	0-15cm	19.9	25.4	5.5	0.183	9.2
were 4x10x6x2=480.	Comparative upland soils, double or triple	Tropics	2016/2017	>30years	0-15cm	19.9	14.4	-5.5	-0.183	-9.2
	(Note 1)						Assuming bulkdesnsity is 1(kg/1iter)			
Java, Indonesia	Government seed sawah plots at 18	Before and mid green revolution	1970-2003	33years	0-20cm	34.5	39.2	4.7	0.14	4.1
(Darmawan et al.	sites	(Farmers routin practices except for	1970-2003	33years	0-100cm	92.7	112.8	20.1	0.61	6.6
2006)	Farmers sawah plots at 22 sites	green revolution technologies)	1970-2003	33years	0-20cm	29.8	41.4	11.6	0.35	11.7
			1970-2003	33years	0-100cm	79.6	114.9	35.3	1.07	13.4
Thailand	Major rice areas, 65 sites	Before and after green revolution	1960s-2010s	50 years	0-15cm	29.8	41.6	11.8	0.24	8.1
(Yanai et al 2021)			1960s-2010s	50 years	0-100cm	79.9	15.5	31.5	0.64	21.7
		(Bulk density data by Piboon in 2011, Carbon mass ratio of (0-100cm/0-15cm)=2.68, which is the data of Bangladesh, was applied)								
Bangladesh	Major rice areas, 31 sites	Before and after green revolution	1967-2010s	50years	0-15cm	23.7	32.3	8.6	0.36	15.3
(Mohsin et al 1997,			1967-2010s	50years	0-100cm	63.5	86.5	23	0.46	7.2
Abe et al 2021)		(Bulk density data and carbon mass ration of (0-100)/(0-15cm)=2.68, which is the data in 1997 by Mohsin et al.)								
United Kingdom	Hoosfield site, upland Spring barley	35t/ha/yr Farm Yard Manure(FYM)	1852-1882	30years	0-40cm	30.7	59.9	29.2	0.97	31.7
(Poulton et al 2018)	(Rothamsted)	(1) line in Fig.32	1882-1913	31years	0-40cm	59.9	75.5	15.6	0.503	8.4
(Jenkinson and	Forested original soil carbon stock was	(1) line in Fig.32	1913-1946	33years	0-40cm	75.5	76.3	0.80	0.024	3.2
Johnston, 1977)	estimated to be **80-150 Mg/ha** (Falloon	(1) line in Fig.32	1946-1975	29years	0-40cm	76.3	86.8	10.5	0.36	4.7
(Fig. 32(b))	et al, 1998)	No manure after 1872,(2) line in Fig.32	1872-1975	103years	0-40cm	52.5	41.4	-11.1	-0.108	-2.1
		No manure,NPK;lime,(3) line in Fig.32	1852-1975	123years	0-40cm	30.7	28.4	-2.3	-0.019	-0.61
		No manure,unfertilized,(4)line in Fig.32	1852-1975	123years	0-40cm	30.7	25.9	-4.8	-0.39	-1.3
United Kingdom	5-year arable crops including root crops	8t/ha/y FYM applied in 1938-1960s	1938-1960s	30.5years	0-40cm	37	37	0	0	0
Woburn experiment	5-year arable including 1-year hay	8t/ha/y FYM applied in 1938-1960s	1938-1960s	30.5years	0-40cm	37	40.2	3.2	0.105	2.8
(Rothamsted)	3-year lucerne ley followed by 2-year arab	8t/ha/y FYM applied in 1938-1960s	1938-1960s	30.5years	0-40cm	37	43.4	6.4	0.21	5.7
(Poulton et al 2017)	3-year grazed clover ley, then 2-year arable	8t/ha/y FYM applied in 1938-1960s	1938-1960s	30.5years	0-40cm	37	50.1	13.1	0.43	11.7
Morrow plot,USA	The plots were begun on virgin grassland	Corn/oat/legume/manure (1) in Fig.32	1875-1997	122years	0-40cm	113	76.2	-36.8	-0.302	-2.7
(Darmody and Peck	soil in 1876	Continuous corn/manure (2) in Fig.32	1875-1997	122years	0-40cm	113	47.9	-65.1	-0.53	-4.7
1977)	Amount of manure was 4.5 t/ha/y	Corn/oat/legume/no-manure(3),Fig.32	1875-1997	122years	0-40cm	113	43.9	-69.1	-0.57	-5.01
(Fig. 32(a))		After 1968 (3)+Lime+NPK (3f), Fig 32	1968-1997	29years	0-40cm	48.4	58.9	10.5	0.36	7.5
		Continuous corn/no manure (4) Fig.32	1875-1997	122years	0-40cm	113	31.6	-81.4	-0.67	-5.9
		After 1968 (4)+Lime+NPK (4f), Fig 32	1968-1997	29years	0-40cm	36.8	38.9	2.1	0.07	2.0

(2) Carbon sequestration rates of upland soils have lower than and carbon emission rates upland soils have higher than those of irrigated sawah platform (Fig. 30-32 and Table 6) either farm yard application (FYM) or not.

(2)-A: Carbon sequestration increases significantly, higher than “4per1000”, when alluvial lowlands are used for irrigated sawah rice cultivation compared to when they are used for upland crops cultivation, major limitation to achieving “4 per 1000” (Poulton 2017) (Figs. 30 and 31 and Table 6 for Japan, China, Indonesia, Thailand and Bangladesh)**.**

(2)-B: Green revolution technology under irrigated sawah platform for rice cultivation can intensify carbon sequestration in Asia (Table 6, Java of Indonesia, Bangladesh, and Thailand)

(2)-C: Newly developed upland farming soils are always carbon dioxide emission source by rapid decomposition of humus of original forest or grass land soils (Fig.30).

(2)-D: No carbon sequestration and net emission except for heavy application of farm yard manure (more than 20-35ton FYM/ha/y) to the upland soils. Organic carbon accumulates significantly in upland soils only when their organic carbon content has been reduced to less than 30-50% of the initial organic carbon content of the pioneer site (see ① line in Figure 31. Numerical data of these (1) line is shown in Table 6, Hoosfield site of Rothamsted (1) line).

(Special note on the reason 3)

Table 7 CH_4 and N_2O emissions and soil organic carbon sequestration rates (SOCSR), their estimated global warming potentials (GWP), and greenhouse gas intensities (GHGI) under different water management strategies (Cited from Wu et al 2018)

Treat-ments	Emission rate kg CH_4 ha^{-1} yr^{-1}	Emission rate kg N_2O ha^{-1} yr^{-1}	SOCSR kg C ha^{-1} yr^{-1}	Grain yield kg ha^{-1} yr^{-1}	GWP(1) kg CO_2-eqv ha^{-1} yr^{-1}	GHGI kg CO_2-eqv kg^{-1}grain
F-RF	112 ± 19c (3136 ±532CO_2-eqv)	0.62 ± 0.09a (164±24CO_2-eqv)	642 ± 66c (2356±242CO_2-eqv)	8951 ± 173b	944± 244c	0.11± 0.03c
F-D-F	376 ± 15b (10528±420CO_2-eqv)	0.29 ± 0.05b (77±13CO_2-eqv)	1072 ± 18b (3934±66CO_2-eqv)	10244 ± 233a	6671± 385b	0.65± 0.04b
CF	805 ± 16a (22540±448CO_2-eqv)	-0.01± 0.00c (-3±0CO_2-eqv)	1292 ± 64a (4741± 234CO2-eqv)	10886 ± 283a	17796± 469a	1.63± 0.04a

Foot note (1): Original Wu et al’s (2018) GWP and GHGI estimates was modified based on the IPCC fifth edition, i.e., GWP=28xCH_4 + 265xN_2O -SOCSR x44/12 (kg CO_2-eqv $ha^{-1}yr^{-1}$). Wu et al (2018) applied conversion factor 34 for CH_4 and 298 for N_2O

As shown in Table 7, irrigated sawah platform emits CH_4 during flooding rice cultivation. However emission rate of CH_4 changes considerably depend on the water control difference. In the table 7, CF means year round continuous flooding, F-D-F means flooding in rice season, except drainage at midseason and harvest time, and F-RF means flooding for transplanting and tillering with no further irrigation. Water saving farming with appropriate intermittent irrigation can control CH_4 and N_2O emission.

In Japan (MAFF 2020), relative annual contribution of CH_4 emission in agricultural sectors were as follows, from irrigated sawah rice 12million tons of CO_2 equivalent (6MgCO_2/ha/y and from animal manure and enteric emission 10million tons of CO_2 equivalent. Major emission of N_2O is come from upland crops, i.e, 9.65 million tons of CO_2 equivalent and from animal manure. Since majority of feeds, such as maize and sorghum are imported, livestock related emission can contribute to upland farming, total emission of CH_4 and N_2O by upland farming is 10+9.65= 19.65milion tons. Irrigated sawah is 12 million tons. The amount of carbon sequestration by both sawah and upland soils is not taken into account.

(Reason 4): Sawah platform system has dam and groundwater recharge function to improve water cycling and water balance in SSA.

Figure 33 shows African characteristic hydrology, i.e., evaporation and ground water contribution are higher than other regions of the earth, such as Asia. It is necessary to research a wide range of uses and enhance the multi-functionality of sawah systems to fit African-specific hydrology to enhance sustainable water use in African agriculture. As shown in Table 8 and 32, dam function and groundwater recharge function of sawah platform system need special attention for the sustainable development of the flood plains and inland deltas in Sudan savannah zone.

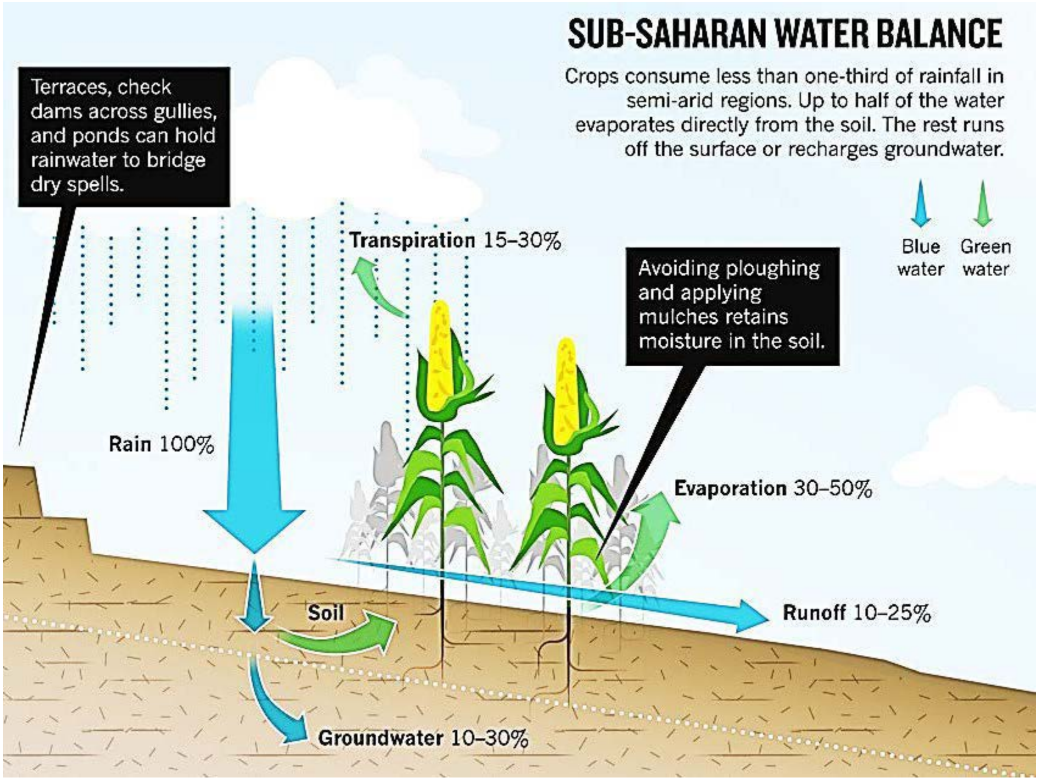


Fig.33. Hydrological characteristics and possible strategy and technological measures for upland crops in Sub-Saharan Africa by Rockstrom and Falkenmark (2015).

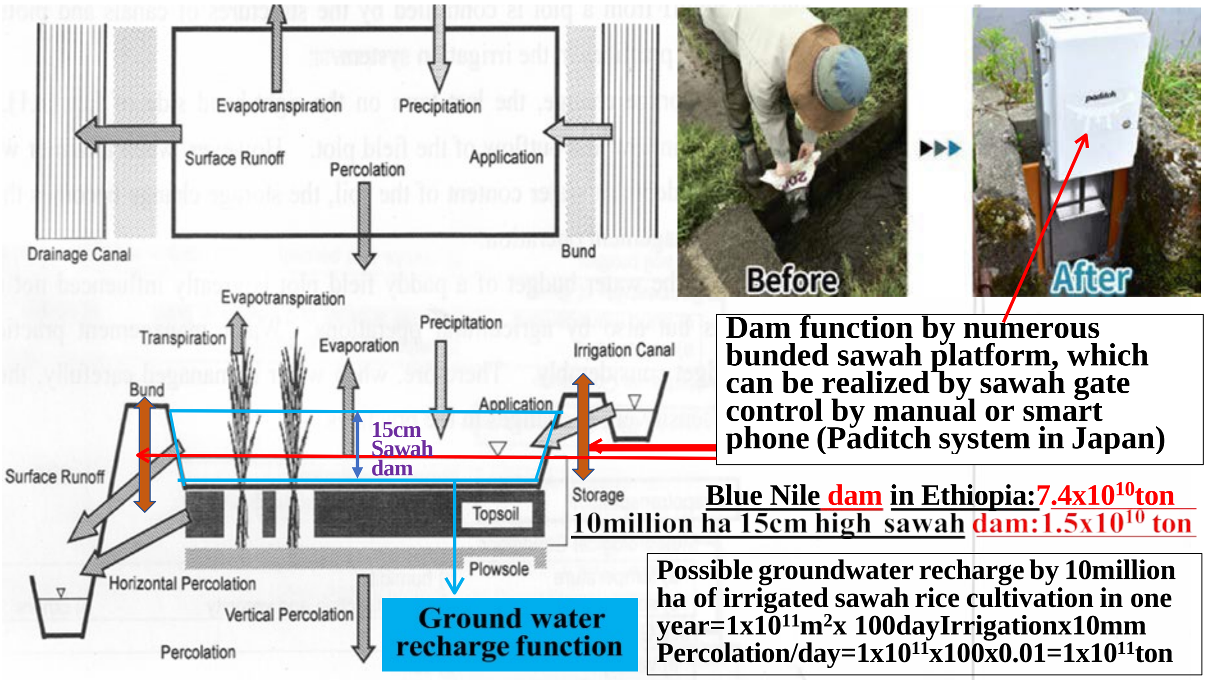


Fig.34. Future possible lowland strategy and technological measures by irrigated sawah platform to solve water balance in Sub-Saharan African agriculture (Drawing was cited by Watanabe 1999, Paditch photos were cited https://paditch.com)

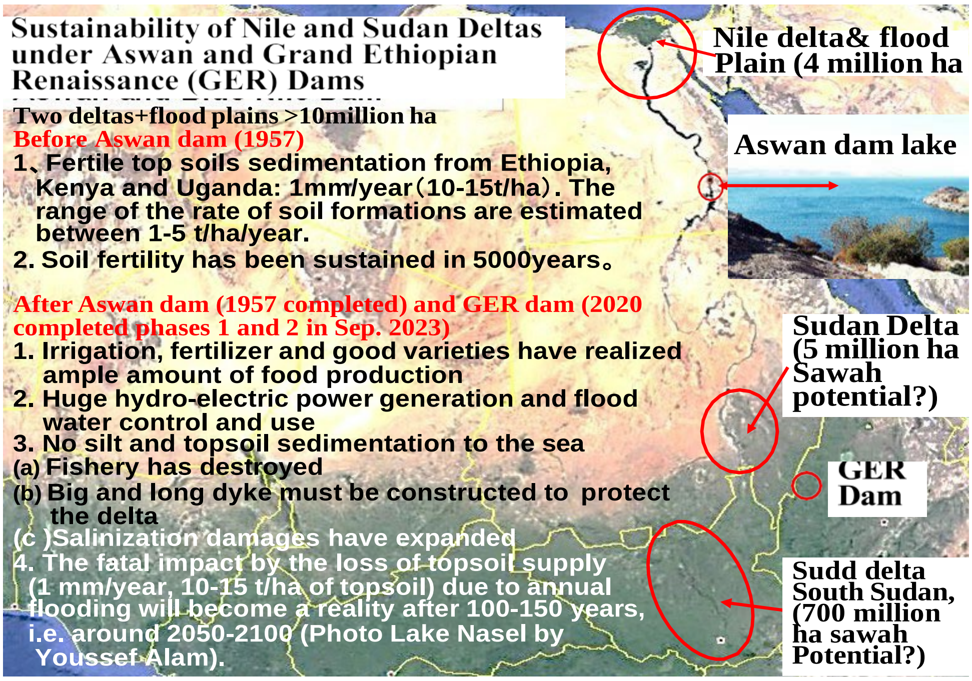


Fig. 35. Sustainability of The Nile River System is under water balance and soil sustainability challenge.

10. Multi functionality of Sawah platform system

Supplementing the sawah hypothesis2 and its three main arguments and empirical data described so far, the sawah platform system has very diverse functions, as shown in Table 8. Sawah platform is a foundation for intensive, diverse and sustainable biological resources of rice and related crops and fish, birds and forests. Sawah platform is a strategic infrastructure to combat global warming and other environmental problems. The *sawah* ecotechnology can improve irrigation and fertilizer efficiency. Thus, it can improve water shortages and poor nutrition (mineral components such as Ca, Mg and Si, plus the three fertilizer components N, P and K in particular.), and neutralize acidity and alkalinity to improve micronutrient supplies.

Sawah platforms are multifunctional wetlands and are defined by the Ramsar Convention as one of the wetlands to be protected, which include lakes, reservoirs, springs, sawah (rice paddies), detention ponds, groundwater systems, salt marshes, mangrove forests, tidal flats, seaweed beds and coral reefs (Ramsar COP10, 2009).

Table 8. Multi Functionality of Sawah platform system and sawah ecotechnology

I. Intensive, diverse and sustainable nature of productivity

(1) Weed control

(2) Nitrogen fixation ecosystems: 20 to 200kgN/ha/year

(3) To increase Phosphate availability: concerted effect on N fixation

(4) pH neutralizing ecosystems: to increase micro nutrient availability

(5) Geological & irrigation fertilization: water, nutrients and topsoil from upland

(6) Various sawah based farming systems.

(7) Fish and rice, Goose and sawah, Birds and sawah, Forest and Sawah

II. To combat Global warming and other environmental problems

(1) Carbon sequestration through control of oxygen supply. Methane emission under submerged condition. Nitrous oxide emission under aerobic rice

(2) Watershed agroforestry, SATOYAMA, to generate forest at upland and to conserve bio-diversity

(3) Sawah systems as to control flooding by enhance dam function through bund management

(4) Sawah system as ground water recharge system and to soil erosion control

(5) Denitrification of nitrate polluted water

III. To create cultural landscape and social collaboration

(1) Terraced sawah as beautiful cultural landscape

(2) Fare water distribution systems for collaboration and fare society

Upper photo of Fig.36 shows sawah platform system of Ifugao people, Philippines. The photo is cited from Koudansha Co. Ltd (1998). The site is selected as one of the world heritage of UNESCO convention (Unesco 2023).The lower photo of Fig.36 is cited from the book by Helmi and Lueras (1990). “The sinuous contours of sawah (rice paddies fields), north of the West Coast town of Tabana appear like layered grand pianos of along the lower slopes of Gunung (Mt) Batukau”. Two red circles show two farmers working on a sawah plot. Four brown circles show rice nursery ready for transplanting.
The terraced rice fields in Ifugao and Bali are irrigated sawah fields developed on relatively steep terrain, but all sawah plots have been carefully levelled to less than ±5 cm soil surface within one plot. As seen in the photo, the watered sawah fields appear to shine like a mirror. This facilitates water management, even on steep slopes, and young seedlings of about 15 cm are easy to transplant and establish, facilitating weed management and soil erosion control.

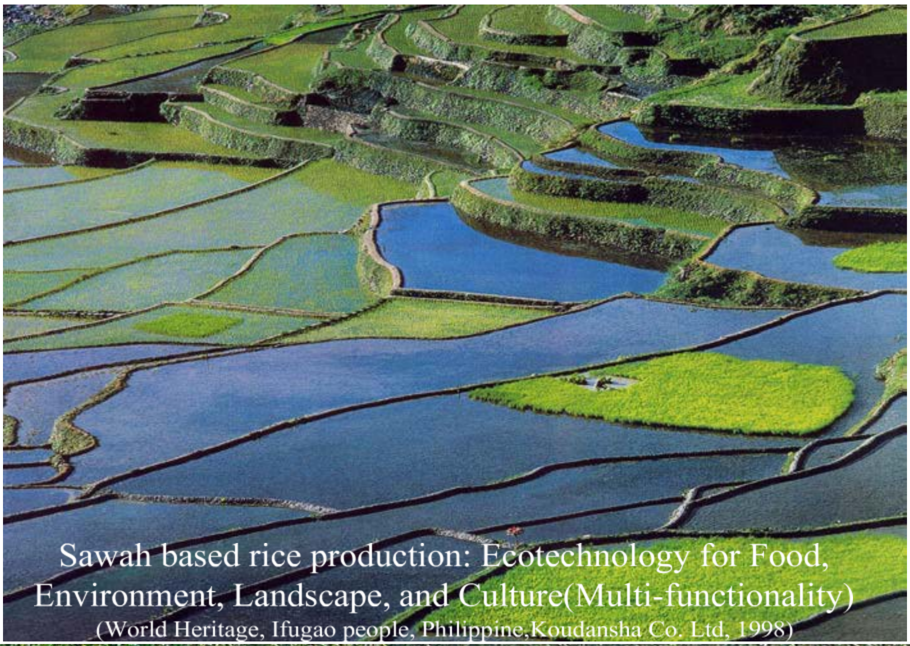


Fig. 36. Two photos are extremely beautiful irrigated sawah platform system for rice cultivation. Top photo showing terraced irrigated sawah rice fields in Ifugao, Philippines (adapted from Kodansha Pub. Co. Ltd, 1998. Estimated location 17.143N 121.075E. Photo below shows a highly developed irrigated sawah platform system in Bali, Indonesia (adapted from Lueras and Helmi 1989). Two red circles show two farmers working in a sawah fields. Four green circles show rice nursery ready for transplanting.

11. Comparative Evaluation of Six ongoing Major Strategies for Rice Revolution in SSA

What is the core strategy to realise the rice green revolution in SSA? Figure 35 shows six ongoing strategies to realise the rice revolution in Sub-Saharan Africa (SSA). The figure indicates yield performances of various improved and traditional rice varieties under both low input and high input as well as poor water control of bushy open farmlands and good water control of improved farmland infrastructure. The figure is also indicating various advantages, such as higher yield, good water control, and improvement of farmland infrastructure, as well as disadvantages, such as lower yield, poor water control, bushy open farmland, various costs of investment, development, maintenance, rehabilitation, training, and labour as well as both environmental and social degradation such as land grab, land conflict and widen the gap between rich and poor, dam damage, forest destruction and topsoil erosion.

A Strategy: Biotechnology priority, such as upland NERICA targeting current bushy open non-consolidated farmlands. As seen in line A in the figure, even good high-yielding or short-season varieties sustainable paddy yield cannot reach >3 t/ha even under high input agronomy. Therefore, this strategy cannot be core strategy to realise the rice revolution. This strategy assumes the core technology is biotechnology. This is the mistaken strategy that good variety can solve major low productivity problems in SSA. The upland rice priority strategy of AfricaRice might come from the misunderstanding that non-sawah wetland rice cultivations are common in West Africa as upland rice cultivations. Following the 3rd Tokyo International Conference on African Development (TICAD III) in 2003, the Japanese government intensified its efforts to support the spread of NERICA rice. However, the strategy for upland NERICA rice dissemination is now at a standstill. If this upland NERICA strategy has been pushed strongly to disseminate using ODA budgets like in Uganda and Guinea, without proper soil and water conservation measures, such sawah system, soil degradation will be seriously widespread.

Agriculture needs good environments and good varieties. Therefore, we have to improve both farmlands with ecotechnology and seeds with biotechnology. Both technologies have to be researched, developed and innovated in good balance. Biotechnology aims to improve varieties through breeding, i.e., genetic improvement, i.e., DNA improvement. Its operational platform is cell of organisms. While the target of ecotechnology is to improve the growing ecological environment through sawah technology research and farmland infrastructure consolidation, that is, improvement of water cycling and soil condition. The target is soil and water. The operational platform is lowland sawah, upland farms and forests in watersheds.

B Strategy: Introduction of Asian Green Revolution Technology. As seen in line B in the figure, this strategy is only effective on the irrigated sawah fields of quality infrastructure consolidation. Although this strategy assumes the three green revolution technologies of the Asian green revolution, that is, high-yielding varieties, fertiliser/agrochemicals and irrigation, must be successful too, this is the mistaken strategy. As we explained in the Sawah hypothesis (1) that the success of the Asian green revolution was based on the prehistory that the sawah systems had been developed by farmers before green revolution technologies arrived in the 1960s during the last hundreds and thousands of years. The same thing is true of the British Agricultural revolution in the 18th century, which was realised based on the long-continued enclosure movement during the 15th to 18th centuries. As discussed in this paper, Sawah hypothesis (1) for lowland rice cultivation and the enclosure for upland cultivation is the same prerequisite infrastructure to apply green revolution technologies and evolve agricultural sciences and technologies. Unfortunately, SSA has no such history because of the globalization of the Western countries from the 15th to the independence year of the 1960s. The 500 years of the slave trade and colonial rule had disturbed such nation-building groundwork. Thus, SSA needs innovative technology to break through the two big barriers of both area and time, that is. 50 million ha of irrigated sawah system development by 2050, several centuries to shorten to several decades, before the explosion of the population bomb.

C Strategy: Introduction of Egyptian Style Dry Season rice or Advanced Agronomy and Hybrid Seeds Technologies for Super High Yield. As described in Sawah Technology (5) Kebbi Rice Revolution, portable pump irrigation gives the best option to realise the highest paddy yield, 6–7 t/ha, even under standard sawah quality. However, as seen the line C in the figure, these strategies have only reasonable cost performance in the fields with advanced sawah of quality infrastructure consolidation in the region and countries with no more frontiers space for new sawah development such as System rice intensification technology (SRI) in Madagascar and Asian countries. During 1949–1968, the Japanese government had been organised a national competition for Japan's No.1 paddy yield farmer, minimum 1000 m^2 area of sawah plot. The data were between 11–14 ton of paddy per ha (1100–1400 kg per 1000 m^2), which farming skills were somewhat similar to the SRI farming technology (Mototani 1989, Horie 2005, Tsujimoto 2015). However, among the estimated potential irrigated rice land, sawah, 50 million ha, and only 2 million ha, less than 5%, are irrigated, including micro sawah plots. Thus, the C strategy has no priority and can be a very limited impact on increasing paddy production currently.

In addition to this, we have to consider the amount of input. At the moment, SRI may double the yield, but labour costs might have to triple. Hybrid seeds are expensive. Rice farmers in SSA have a limited budget to buy expensive hybrid seeds yearly. These will be an additional heavy burden on most rice farmers in SSA.

D Strategy: Contractors-based Irrigated Sawah System development using ODA funds such as World Bank, African Development Bank and other Donors. As seen in the curved line D and as shown in the Table below, although many rice sector people understand the importance of irrigation, farmers, extension officers, engineers, scientists and policymakers in SSA have no or very limited knowledge, experience, and skills in irrigated rice cultivation, both large-scale and small-scale irrigation projects, typically created by contractors under Official Development Assistance (ODA), are very costly because of dependence on heavy engineering works and outside expertise (FAO 1998, Wakatsuki et al. 2001, JICA 2008, MOFA and AfDB 2008, Fujiie 2011). Investment costs for development, management, rehabilitation, and training are all expensive compared to Asian countries. In addition to the direct investment cost, corruption is widespread. The development operation is used to continue longer than five years. During the development period, farmers cannot cultivate rice. Due to the high construction costs, the economic returns remain negative for a long period of time (20–30 years).

Environmental and social degradation are often serious, such as land grab, land conflict, expansion income disparities, lowland submergence by the dam, topsoil erosion, and forest destruction.
ODA projects are likely to destroy the autonomy of the African government. Project ownership remains with the government (engineers) rather than the farmers because they cannot develop the systems alone. Therefore, neither the development nor the management is sustainable.

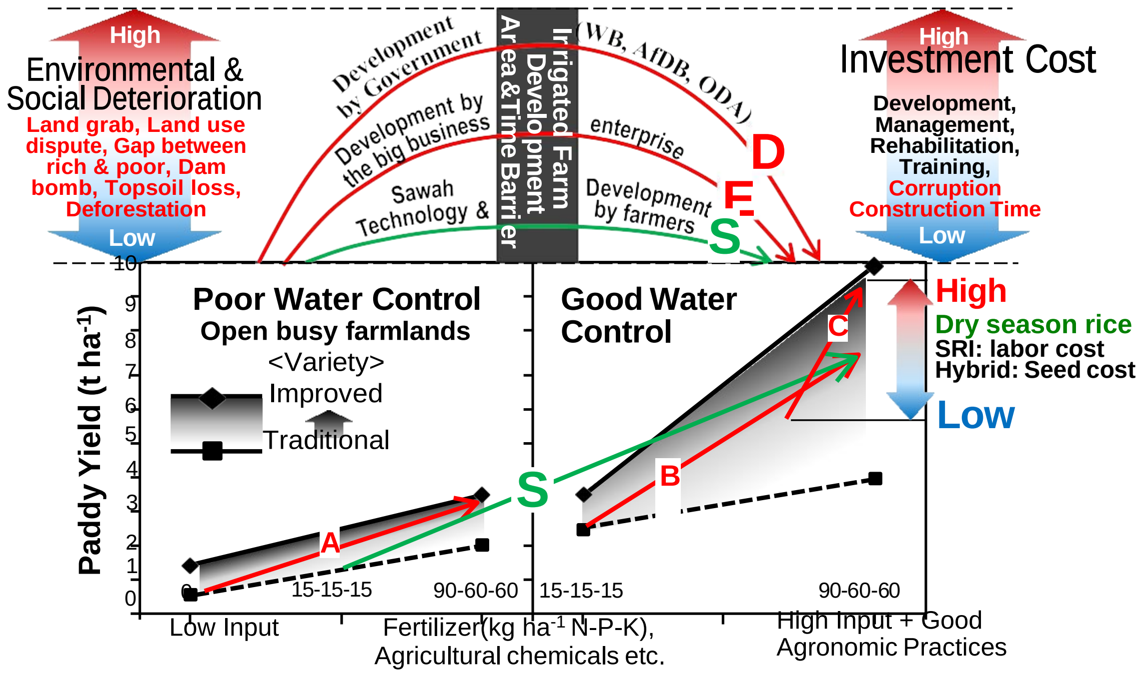


Figure 35. Six Strategies to Increase Paddy Yield and Production in SSA

A-type strategy: Upland NERICA technology
B-type strategy: Asian Green Revolution technology
C-type strategy: Hybrid seed and System Rice Intensification
D-type strategy: Contractor-based ODA irrigation/drainage development
E-type strategy: Irrigation by private big business enterprises
S-type strategy: Sawah technology with sustainable mechanisation

E Strategy: Irrigated Sawah System Development by Private Big Business Enterprise. Dr Adesina (2013), Federal Minister of Agriculture and Rural Development, Nigeria, declared the new policy that Agriculture should treat as a moneymaking business and not as a charitable development project, which had often expanded corruption last decades. The private business-based irrigated sawah system developments are more efficient than ODA-based projects in terms of the investment cost for development, management, rehabilitation and training with the most advanced mechanized farming, like the example of Olam farm at Benue State, Nigeria. Total investment was $110 million targeting 6000 ha of irrigated sawah development pumping water from Benue River, which can double cropping, 10,000 ha annual cultivation and 60,000 tons of paddy and 36,000-ton milled rice. The project started in 2013 (Olam Nigeria Home page 2016, Rockefeller foundation 2013). Because the site is on the floodplain of the Benue River, some sawah plots suffered from flood damage. Thus current irrigated area is estimated to 5000ha in 2022. The farm is equipped with an airport for direct seeding and pesticide spraying from aeroplanes. Laser leveller-attached tractors are levelling and cultivating. Each tractor can manage 20-40 ha of sawah plot with 0.5ha to 5 ha size. **(Note: Skilled sawah farmers can cultivate irrigated sawah rice 10-15 ha per year in Kebbi and Bida area in Nigeria in 2020)**. Combine harvest paddy, then milled at the farm. It is a fully mechanized integrated rice farm except for weeding. Because of direct seeding, manual weeding is necessary. Hundreds of women are working on picking weeds by hand.

The cost-effectiveness is better than the ODA-based development as shown in Table 9 below. The development cost per ha of irrigated sawah is estimated $ 110 million/5000 ha = $22,000/ha, including huge mill cost. If double cropping is realised, the cost will be $ 110 million/10,000 ha = $11,000/ha. The total annual milled rice selling price will be 0.6 (milling ratio) × 6 × 10000 × $500 (per ton) = $18 million. Since the running cost per ha for paddy production per ha is about $500-600, the total running cost will be $ 5.5 million, the annual profit becomes higher than $10 million. The investment cost can be recovered in 110/10 = 10 years. This is about doubly efficiency than that of the ODA-based "charitable development project." However, we have to wait for the final evaluation still some years after. As of 2023, the project has passed just 10 years, but Olam Co. Ltd. looks has no plans for further expansion, and instead seems to be focusing on contracting with rice farmers in the surrounding area to operate as a rice miller business. Although the Olam farm is expanding out grower farmers training program, the farm is operating the most advanced mechanised rice farming. However, most surrounding rice farmers operate by hand hoe and non-sawah rice farming. Thus, the investment and technology gap will not be able to fill. In addition, the private farms will enclose a big, good lowland of the nation, that is., land grab. Therefore, numerous small farmers, the most important national resource, can be excluded from autonomous rice cultivation and empowerment.

Table 9: Comparison of endogeneous farmers' site-specific personal irrigated sawah system development and sawah based rice farming(Sawah technology) with large- and small-scale contractor (ODA) style developments, and traditional rice cultivation system in various lowlands of Nigeria and Ghana (2022).

	Large-scale development	Small-scale development	Sawah technology	Traditional system
Development cost ($/ha)	**10000–30000**	**10000–30000**	**1000-2000**	**30–60**
Gross revenue ($/ha)†	1000–1500	1000–1500	1000–1500	250–500
Paddy Yield (t/ha)	4–6	4–6	4–6	1–2
Running cost, including machinery ($/ha)	500–600	500–600	500–600	400–250
Farmer participation	Low	Medium–High	High	High
Project ownership	Government	Government	Farmer	Farmer
Adaptation of technology	Long	Medium to short	Medium to short, needs intensive demonstration and on-the-job training (OJT) program	Short
Technology transfer	Difficult	Difficult	Easy	Few technology transfer
Sustainable development	**Low(heavy machinery used by contractors in development)**	**Low to medium**	**High (farmer-based and small power-tiller used in development and management)**	**Medium**
Management	**Difficult**	**Difficult**	**Easy**	**Easy**
Adverse environmental effect	High	Medium	Low	Medium

† Assuming 1-ton paddy is worth US$ 250; one power-tiller costs US $ 2500-3000 in West Africa depending on the brand quality and accessories (2022 values). Selling prices of one unit of power tiller are $1500-$2500 for farmers in Asian countries.

S Strategy: Sawah Technology for Endogenous Sawah System platform Development and Sawah-Based Rice Farming with Sustainable Mechanisation. As described in this paper, SSA needs irrigated sawah platform development for the rice green revolution. And SSA needs innovative technology to break through the two big barriers of both area and time, that is, 50 million ha of irrigated sawah system development by 2050, several centuries to shorten to several decades before the explosion of the population bomb. Among the six strategies, S strategy will be a core to make possible these two targets above. However various supports of the governments of SSA countries, ODAs and NGOs are important, with the proactive efforts of countless African rice farmers as a pillar of support. Our companion paper, "Sawah Technology「アフリカ水田農法」 (5Paper): Practices and Potential of Irrigated Sawah System Development and Sawah Based Rice Farming by Farmers' Self-help Efforts", is described in detail. Sawah Technology (6Paper): Kebbi Rice Revolution described the first model of SSA's endogenous green revolution: successful integration between the sawah technology and Egyptian stile dry season ultra-high-yielding irrigated rice farming.

Sawah technology offers low-cost irrigation development and water control for sustainable rice intensification with a sustainable paddy yield of more than 4–5 t/ha in 5–15 ha, i.e., 20–75 ton of annual paddy production using one power tiller per farmer or farmers' group. This will empower small rice farmers economically, i.e., 20–75 tons of paddy price will be $500–$20,000 (assuming $250 per ton of paddy) if milled in 0.625% milling ratio and $400–$500 per ton of milled rice, then the total selling price will be $5,00–$25,000. While new sawah development cost will be $1000–2000 per ha, including power tiller cost, $2500–$3000 per set, and the running cost of sawah-based rice farming will be 50% of the total selling price. Therefore, the investment cost of 5 ha of sawah will be $5000–$10000, and the annual profit will be 20–25 tons of paddy, $5000–$6000. This means the investment can recover within 2–3 years, which can compare 10–30 years of private business enterprises and ODA-based development (D and E strategies). Even though this investment cost is too high and the recovery years of 2–3 are too long to manage for most small rice farmers in SSA. Therefore, special policy by governments of SSA is necessary.

13. References

Abe S and Wakatsuki T. 2011. *Sawah* ecotechnology triggers rice green revolution in Sub-Saharan Africa. *Outlook on Agric*ulture 40:221-227

Abe S, Ali M, and Wakatsuki T, 2022. Changes in Paddy Soil Fertility in Bangladesh Under the Green Revolution, In "*Changes in Paddy Soil Fertility in Tropical Asia under Green Revolution, From the 1960s to the 2010s*, Chapter 6. Page 81-112", edited by Yanai J, Tanaka S, Nakao A, and Abe SS, Springer Nature Singapore Pte Ltd. Singapore

ADAS, 2002. Development of a database of agricultural drainage Defra Project Code ES0111, ADAS is a UK-based independent agricultural and environmental consultancy and provider of rural development and policy advice. ADAS is rebranded name (in1971) of the UK's National Agricultural Advisory Service (NAAS) established in 1946, which was privatise in 1997.

Adesina A. 2013. Transforming Nigeria's Agriculture, Speech delivered by Hon Minister of Agriculture and Rural Development, Federal Republic of Nigeria, at the Inauguration of the Agriculture and Food Security Center of the Earth Institute of Columbia University, New York, USA, September 10, 2013. http://agriculture.columbia.edu/events/past-events/inaugural-seminar-the-nexus-of-agriculture-environment-and livelihoods/transforming-nigerias-agriculture/

Africa Rice 2013. Africa Rice center Annual report 2012, p14-16, Africa-wide rice Agronomy Task force, http://www.africarice.org/publications/ar2012/AfricaRice-AnnualReport-2012.pdf

Africa Rice 2014a. Sawah Technology introduction under Japan and AfricaRice, 35 years of strategic partnership for rice development, http://africarice.org/publications/Japan%20and%20AfricaRice.pdf

Africa Rice 2014b. High Scalability of Sawah Technology in Sub Sahara Africa, http://www.kinki ecotech.jp/download/AfricaRice-AnnualReport-2013_p6,14-15,41-42.pdf

Africa Rice 2015. Scaling up of Sawah Technology in Benin and Togo, http://www.kinki-ecotech.jp/download/AfricaRice-AnnualReport-2014_p11-12,32-34.pdf

Africa Rice 2016. Sawah Technology for Rehabilitating the rice sector in post-conflict countries of Liberia and Sierra Leone, http://www.kinki-ecotech.jp/download/AfricaRice-AnnualReport-2015_p16,20.pdf

Africa Rice 2018. Out-scalling Smart-valleys to boost rice productivity, AfricaRice 2016 Annual Report published in 2018, http://www.kinki-ecotech.jp/download/AfricaRice-AnnualReport-2016_p15,16.pdf

Agrawal GK, Takeda S, Abe K, Miyano A, Hirochika H, Kitano H, Ashikali M and Matsuoka M. 2004. An overview of gibberellin metabolism enzyme gene and their related mutants in rice. *Plant Physiol* 134: 1642-1653.

AHDB 2018. Filed drainage guide, Principles, installation and maintenance, Agriculture and Horticulture

Development Board, https://projectblue.blob.core.windows.net/media/Default/Imported%20Publication%20Docs/Field%20drainage%20guide%200818.pdf
Ahlemeyer J and Friedt W, 2010. Progress in Winter Wheat Yield in Germany -What's the Share of the Genetic Gain? Tagung der V e r e i n i g u n g d e r P f l a n z e n z ü c h t e r u n d Saatgutkaufleute Österreichs 2010, 61, 19-23
Allen RC. 1999. Tracking the agricultural revolution in England, *Economic History Review*, LII(2) :209-235
Allen RC. 2008. Agriculture during the industrial revolution, 1700-1850, in Cambridge Histories online, chaper 4:96 116, Cambridge University Press
Apostolides A, Broadberry S, Campbell B, Overton M, and Van Leeuwen B, 2008. English Agricultural Output and Labour Productivity 12501850: Some Preliminary Estimates http://www.basvanleeuwen.net/bestanden/agriclongrun1250to1850.pdf
Archaeological Institute of Kashihara, 2019. Local briefing materials on Nakanishi Archaeological excavbationsite, Gose City, Nara Prefecture, 31st Survey, November 23, 2019, http://www.kashikoken.jp/under_construction/wp-content/uploads/2019/11/ef30b483aa71875485b417a11d37441f.pdf
Arahata K, 2014. 荒幡克己「減反 40 年と日本の水田農業」、農林統計出版、817 頁
Asahi News Paper, 1971. 20 years history of Japanese No.1 rice farmer, Published by Asahi Shimbun Agricultural Award Secretariat(朝日新聞社農業賞事務局)
Ashikali M, Sasaki A, Ueguchi-Tanaka M, Itoh H, Nishimura A, Datta S, Ishiyama K, Saito T, Kobayashi M, Khush SD, Kitano H and Matsuoka M. 2002. Loss of function of a rice gibberellin biosynthetics gene, GA20 oxidase (GA200x-2), Led to the Rice 'Green Revolution'. *Breeding Sci* 52: 143-150.
Bayer C, Mielniczuk J, Amado T, Martin-Neto L, and Fernandes S, 2000. "Organic matter storage in a sandy clay loam Acrisol affected by tillage and cropping system in southern Brazil, "Soil and Tillage Research, 54:101-109
Borojevic K and Borojevic K 2005. The transfer and history of "reduced height genes (Rht)" in wheat from Japan to Europe, J. Heredity, 96(4):455-495
Boserup E 1965. The condition of Agricultural Grawth: The Economics of Agricultural Change under Population Pressure, Allen & Unwin, London, pp124
Brady NC and Weil RR, 2014. The nature and properties of soils, 4th edition, Indian Subcontinent Version, Dorling Kindersley (India) Pvt. Ltd, pp1046, Cited page 599
Chalmers AF, 2013. What is this thing called science? 3rd edition, University of Queensland Press, 1999, Japanese translation by Takada K and Sano M, Kouseisha Kouseikaku Co. Ltd, Tokyo, 2013, pp408+XVIII
Darmawan, Kyuma K, Saleh A, Subagjo H, Masunaga T, and Wakatsuki T. 2006. Effect of green revolution technology from 1970 to 2003 on sawah soil properties in Java, Indonesia: I. Carbon and nitrogen distribution under different land management ans soil types. *Soil Sci Plant Nutr* 52:634-644
Darmawan, Shin Abe, Masunaga T, and Wakatsuki T, 2022. Changes in Paddy Soil Properties in Indonesia (Java Island) Under the Green Revolution During the Period of 1970–2003, In "*Changes in Paddy Soil Fertility in Tropical Asia under Green Revolution, From the 1960s to the 2010s*, Chapter 7. Page 113-137", edited by Yanai J, Tanaka S, Nakao A, and Abe SS, Springer Nature Singapore Pte Ltd. Singapore
Dakingari. His Excellency, Alh. Sa'idu, Usman 2013. Growing Agriculture in Kebbi state, paper presented by the executive governor of Kebbi state, , Dakingari at the 19th National Economic summit, Group(NESG) held in Abuja on the 4th September, 2013
Defoer T, Dugué MJ, Loosvelt M, Soklou Worou S 2017. Smart-valleyse :Trainee- facilitators' Manual, 1-134pp, AfricaRice, http://www.africarice.org/publications/smart-valleys/ENsmart_09H-02O.pdf
Douet A, 2012. Breaking New Ground, Agriculture in Norfolk 1914-72, Barwell Print Ltd, Dunkirk, Aylsham NR11 6SU, pp278
Ellis EC, Kaplan JO, Fuller DQ, Vavrus S, Goldewijk KK, and Verburg PH 2013. Used planet: A global history, PNAS, May 14, vol 110, no. 20: 7978-7985, www.pnas.org/cgi/doi/10.1073/pnas.1217241110
Evenson RE and Gollin D. 2003. Assessing the impact of the green revolution, 1960 to 2000. *Science* 300: 758-762.
Enclosure Acts. 2016. Great Britain. http://www4.uwsp.edu/english/rsirabia/notes/212/enclosureacts.pdf
FAO. 2007. Rice situation update as of 31 March 2007. FAO Rice Market Monitor, Vol. X, Issue No. 1. Food and Agricultural Organization of the United Nations. Available at: http://www.fao.org/es/esc/en/index.html
FAOSAT 2013. http://www.fao.org/statistics/en/
Fujiie H, Maruyama A, Fujiie M, Takagaki M, Merry DJ, and Kikuchi M, 2011. Why invest in minor project inSub Saharan Africa? An exploration of the scale economy and diseconomy of irrigation project, Irrig. Drainage Syst. 25:39-60 (DOI 10. 1007/s10795-011-9111-4)
Fujimoto M and Shindo S, 2019. Spatial Variation in the Water Requirement Rate for Paddy Fields in Flat and Lower Areas,
Fukamachi K, Oku H and Nakashizuka, 2001. The change of a satoyama landscape and its causality in Kamiseya, Kyoto Prefecture, Japan between 1970 and 1995, Landscape Ecology 16: 703–717, https://link.springer.com/content/pdf/10.1023/A:1014464909698.pdf

Fukumoto M and Shindo S, 2019. Spatial Variation in the Requirement Rate for Paddy Fields in Flat and Lower Areas, NARO Report, Rural Engineering Research Division, Vo.3, page 1-12, https://agriknowledge.affrc.go.jp/RN/2030927488.pdf, https://doi.org/10.24514/00001146
Greenland DJ. 1997. *Sustainability of Rice Farming*, CAB Int'l, U.K. and IRRI, Los Banos, p. 273.
Geertz C 1963. Agricultural Involution: The Process of Ecological Change in Indonesia, Univ. California Press, Berkeley, CA, p176
Hardin LS. 2008. Meeting that changed the world, Bellagio 1969: The green revolution, *Nature* 455: 470-471.
Hazell P and Wood S. 2008. Drivers of change in global agriculture. Philos. Trans. R. Soc Lond, B. Biol Sci 363: 495-515.
Helmi R and Lueras L, 1990. Bali High, Paradaise from the air, Times Editions, Singapore,
Herdt RW and Capule C. 1983. Adoptin, Spread, and Production Impact of Modern Rice Varieties in Asia, IRRI, Manila, Philippines, p1-54, http://books.irri.org/getpdf.htm?book=9711040832
Hesser L. 2006. *The man who fed the world, Nobel peace prize laureate Norman Borlaug and his battle to end world hunger*. Durban house Publishing Company. Dallas, 263 p, ISBN1-930754-90-6.
Hirose H and Wakatsuki T. 2002. *Restoration of Inland Valley Ecosystems in West Africa.* Nourin Tokei Kyoukai, Tokyo. p. 572. Hirose, S. and Wakatsuki, T. eds., 2002. Restoration of inland valley ecosystems in West Africa. Association of Agriculture & Forestry Statistics, Tokyo, 1-572 pages, Contents and summary, http://www.kinki-ecotech.jp/download/nourinntoukeikyoukaichosho_EN/book_en_contents%20and%20summary_20200212.pdf Chapter 1-4, http://www.kinki-ecotech.jp/download/nourinntoukeikyoukai-chosho_EN/book_en_chapter1-4ed_20200212.pdf Chapter 5-7, References and Index, http://www.kinki-ecotech.jp/download/nourinntoukeikyoukai-chosho_EN/book_en_chapter5-7ed_20200212.pdf
Honma T, 1998. Mechanism of nation building in Japan: Relationship between Sawah (Paddy) field development and population increase. Sankaido Publishing Co., Ltd. Tokyo (in Japanese).
Honya K, 1989. Science of ultra-high yielding rice farming in Japan during 1949-1968 (in Japanese, Tashyukaku Inasaku no Kaimei), Hakuyusha Co.Ltd, Tokyo, 148pp.
Horie T, Shiraiwa T, Homma K, Katsura K, Maeda S and Yoshida H, 2005. Can Yields of Lowland Rice Resume the Increase that They Showed in the 1980s?, Plant Prod. Sci. 8(3): 259-274
Igwe C A and Wakatsuki T 2012. Multi-functionality of Sawah Eco-Technology : Role in Combating Soil Degradation and Pedological Implications, Pedologist, (2012) 178-186
IITA 2008. Bountiful rice harvest from Sawah system, http://www.iita.org/search/ /journal_content/56/25357/48172#.WEtsy7KLTSE
Johnston AE and Poulton PR, 2018. The importance of long-term experiments in agriculture: their management to ensure continued crop production and soil fertility; the Rothamsted experience, European Jounal of Soil Science, January 2018, 69, 113-125, doi:10.1111/ejss.12521
Juo ASR and Lowe JA. 1985. The wetlands and rice in Sus Saharan Africa, Proceedings of an international conference on wetalnd utilization for rice production in Sub Saharan Africa, 4th to 8th of November, 1985, IITA, JohnIbadan, 318p
Kalaizandonakes NG, Gehrke B, and Bredahl ME, 1994. “Competitiveness pressure, productivity growth and competitiveness”, In edited by Bredahl ME, Abbott PC, and Reed MC, “Competitiveness in International Food Markets”, Westview Press, p169-187.
Kato N, 2005. Effects of continuous field rotation between paddy rice and upland soybean on soil fertility, 田畑輪換の継続が土壌肥沃度に及ぼす影響、BULLETIN OF THE NATIONAL AGRICULTURAL RESEARCH CENTER FOR TOHOKU REGION,Tohoku Nogyo Kenkyu Center Kenkyu Hokoku No.103, March 2005, https://www.naro.affrc.go.jp/archive/niaes/techdoc/tsuchimizu/24/9_kato.pdf
Kawaguchi K, Kyuma K, 1977. Paddy soils in tropical Asia. their material nature and fertility. The University Press of Hawaii, Honolulu, p 258
Kerridge Eric 1967. The Agricultural Revolution, Routledge, Taylor & Francis, London and New York, 1-429pp
Koudansha Co. Ltd, 1998. World Heritage of Unesco2023, Ifugao people, Philippine.
Kuhla B and Viereck G, 2022. Enteric methane emission factors, total emissions and intensities from Germany’s livestock in the late 19th century: A comparison with the today’s emission rates and intensities, Science of the Total Envronment, 848(2022)157754, http://dx.doi.org/10.1016/j.scitotenv.2022.157754
Kush G, Wakatsuki T, and Adole GI 2006. CCER on Integrated Genetice and Natural Resources Management, 22 January -10 February, Cotonou, Benin, WARDA
Kwang JS, Thaler EA, and Larsen IJ, 2023. The Future of Soils in the Midwestern United Status. Earth’s Future, 11, e2022EF003104, https://doi.org/10.1029/2022EF003104
Kyuma K. 2004. *Paddy Soil Science*, Kyoto University Press, Kyoto, p. 280.
Lal R and Stewart BA, 1992. Soil Restoration, Advances in Soil Science, Vol.17, 456pp, Springer-Verlag, New York
McGlynn SE, Chadwick GL, Kemes CP, and Orphan VJ. 2015. Single cell activity reveals direct electron transfer in methanotrophic consortia. Nature Vol 526, 22 October 2015 :531-535, doi :10.1038/nature15512
Malthus TR 1798. An Essay on the Principle of Population, as it Affects the Future Improvement of Society, with Remarks on the Speculations of Mr. Godwin, M. Condocret, and other writers, J. Johnson, London, pp3-143
Matsushita H. 2013. Logical Sawah (in Japanese), Nikkei premium series No 196, pp237

Minagawa H and Miyazu S, 2022. Functional evaluation of rice paddy dam fixtures with different characteristics using simulated heavy rain, Journal of the Society of Agricultural and Rural Engineering, Vol.90, No.1, p.I_157-I_165(皆川裕樹・宮津進(2022):模擬豪雨を活用した特徴の異なる田んぼダム器具の機能評価、農業農村工学会論文集、90 巻 1 号、p.I_157-I_165)
Mitsuchi M, 1974a. Pedogenic Characterisics of Paddy Soils and Their Significance in Soil Classification, 低地水田土壌の生成的特徴とその土壌分類への意義、農業技術研究所報告B 25: 29-115
Mitsuchi M, 1974b. Characters of humus formed under rice cultivation, Soil Science and Plant Nutrition, 20:3, 249-259, https://doi.org/10.1080/00380768.1974.10433247
Mohapatra S. 2016. A SMART choice for Africa's inland-valley rice farmers, http://ricetoday.irri.org/a-smart-choice for-africas-inland-valley-rice-farmers/, in ricetodya.irri.org
Nakao A, Masai F, Timpas N, Medina S, Abe S, Tanaka S, Yanai J, 2021. Changes in lowland paddy soil fertility in the Philippines after 50 years of the green revolution. SOIL SCIENCE AND PLANT NUTRIT10N 2021,VOL.67, NO.4:446-459, https://doi.org/10.1080/00380768.2021.1947118
Nakao A, Yanai J, and Abe S, 2022. Changes in Lowland Paddy Soil Fertility in the Philippines After 50 Years of the Green Revolution, In "*Changes in Paddy Soil Fertility in Tropical Asia under Green Revolution, From the 1960s to the 2010s*, Chapter 4. Page 48-71", edited by Yanai J, Tanaka S, Nakao A, and Abe SS, Springer Nature Singapore Pte Ltd. Singapore
Nakayama S, 2011.History of Scientific Paradigms (In Japanese), Bele Publishing Co. Ltd, Tokyou, pp302
Nielsen LP, Risgaard-Petersen N, Fossing H, Christensen PB and Sayama M. 2010. Electric currents couple spatially separated biogeochemical processes in marine sediment. *Nature* Vol 463, 25 February 2010| doi:10.1038/nature08790
Nishida M, 2022. Key to Japan's agricultural productivity: Paddy (Sawah) soil problems and direction of their management, *Agriculture* (No. 1685:6-22), 日本の農業生産力の要：水田土壌を巡る問題とその管理の方向性、農業、1685 号、農業懇話会、https://www.dainihon-noukai.or.jp/library/61bc776bb57d7bf14fe411a4/63450f0a4ed620a7226146ca.pdf
NFU Norfolk 100, 2018. A century of Growing, NFU Norfolk marks its first 100 years, https://www.nfuonline.com/archive?treeid=112955
Ofori J, Hisatomi Y, Kamidouzono A, Masunaga T, and Wakatsuki T. 2005. Performance of rice cultivars in various *sawah* ecosystems developed in inland valleys, Ashanti Region, Ghana. *Soil Sci Plant Nutr* 51: 469-476.
Oladele OI, Bam RK, Buri MM and Wakatsuki T. 2010. Missing prerequisite for Green Revolution in Africa: Lessons and the challenges of *Sawah* rice ecotechnology development and dissemination in Nigeria and Ghana. *J. Food Agric Environ* 8: 1014-1018.
Olam Nigeria Home page, 2016. http://olamgroup.com/locations/west-central-africa/nigeria/ http://49tmko49h46b4e0czy3rlqaye1b.wpengine.netdna-cdn.com/wp-content/uploads/2014/07/14June2014-Olam-Rice-Mill-Commissioned.pdf
Okada K and Kanehara M, 2022. Changes and Characteristics of Early Yayoi Paddy Field Remains at Nakanishi and Akitsu Sites, 岡田憲一・金原正明、「中西遺跡・秋津遺跡の弥生時代前期水田遺構の変遷とその特質」 http://www.kashikoken.jp/under_construction/wp-content/uploads/2022/03/kiyo45-okada.pdf
Orr S, Sumberg J, Erenstein O and Oswald A. 2008. Funding international agricultural research and the need to be noticed: A case study of NERICA rice. *Outlook on Agric* 37: 159-168.
Otsuka K and Kalirajan KP. 2006. Rice green revolution in Asia and its transferability to Africa: An introduction. *Dev Econs* 44:107-122.
Otsuka K. 2006. Why can't we transform traditional agriculture in sub-Saharan Africa? *Review of Agric Econs* 28:332 337.
Otsuka M and Kobayasi T, 2004. The rice terraces in China Yunnan, Mainichi News Paper Co. Ltd, pp94 (In Japanese)
Overton Mark 1996. Agrcicultural Revolution in England, Cambridge University press, 1-258pp
Oyediran GO. 1990. *Genesis, Classification and Potential Productivity of Selected Wetland Soils in the Savanna Ecosystem of Nigeria*, PhD Thesis, Obafemi Awolowo University, Ile-Ife, Nigeria, pp1-335, http://www.kinki-ecotech.jp/download/Oyediran1990Ph.D.thesis.pdf
Paditch 2023. Automate water management of sawah plots (TANBO) and dam function management of sawah system (TANBO dam) in the basin by controlling water gates and valves with a smartphone, https://www.youtube.com/channel/UCOGF5eCAIyykn6sAJGxdXwg, https://paditch.com/
Ramsar COP10, 2009, The Convention on Wetlands, https://www.ramsar.org/document/cop10-conference-report
Renkow M and Byerlee D. 2010. The impact of CGIAR research: A review of recent evidence. *Food policy* 35(5): 391-402.
Robinson M and Armstrong AC, 1988. The extent of agricultural filed drainage in England and Wales, 1971-80, Transaction of the Institute of British Geographers, Vo.13, No (1988), pp. 19-28, https://www.jstor.org/stable/622772
Robinson M and Gibson H, 2011. Assessing the status of drainage in the UK: A case study of the Avon and Wensun DTCs and their representativeness with regional and national patterns. Report to ADASA UK Ltd, Center for Ecology and Hydrology, Natural environment Research Council,, https://core.ac.uk/download/pdf/52428.pdf
Rockefelelr Foundation 2013. Rice Nucleus, Olam, Nigeria, Catalytic Innovation in African Agriculture,

http://49tmko49h46b4e0czy3rlqaye1b.wpengine.netdna-cdn.com/wp-content/uploads/2014/01/Rockefeller-Foundation-Nigerian-Rice-Farm-Case-Study.pdf
Rosentreter JA, Laruelle GG, Bange HW, Bianchi TS, Busecke JJM, Cai WJ, Eyre BD, Forbrich I, Kwon EY, Maavara T, Moosdorf N, Najjar RG, Sarma VVSS, Van Dam B and Regnier P, 2023. Coastal vegetation and estuaries are collectively a greenhouse gas sink, *Nature Climate Change*, https://doi.org/10.1038/s41558-023-01682-9,
Salagado M. 2012. Agricultural revolution, http://www.slideshare.net/maggiesalgado/agricultural-revolution 13173417, and -33117637
Sanchez P. 2002. Soil fertility and hunger in Africa. Science 295: 2019-2020.
SHIRATO Y, YAGASAKIi Y, and NISHIDA M, 2011. Using different versions of the Rothamsted Carbon model to simulate soil carbon in long-term experimental plots subjected to paddy-upland rotation in Japan, Soil Science and Plant Nutrition (2011), 57, 597-606, https://doi.org/10.1080/00380768.2011.591284
SMART 2013 https://smartiv.wordpress.com/
SMART 2016 https://smartiv.wordpress.com/about/
Sumida H, Kato N, and Nishida M, 2005. Depletion of soil fertility and crop productivity in succession of paddy rice-soybean rotation, BULLETIN OF THE NATIONAL AGRICULTURAL RESEARCH CENTER FOR TOHOKU REGION,Tohoku Nogyo Kenkyu Center Kenkyu Hokoku No.103:39-52, March 2005, https://www.naro.go.jp/publicity_report/publication/archive/files/tohoku103.pdf
Takakai F, Hatakeyam K, Nishida M, Nagata O, Satou T, and Yoshihiro Kanetau Y, 2021. Effect of the long-term application of organic matter on soil carbon accumulation and GHG emissions from a rice paddy field in a cool-temperate region, Japan-ll. Effect of different compost applications, *SOIL SCIENCE AND PLANT NUTRITI()N*, 2020,VOL.66,NO.1: 96-105, https://dol.org/10.1080/00380768.2019.1681881
Tanaka S, Saito H, Kajiwara N, Paing TN, Yusoff KHM, Abe S, Nakao A, Yanai J , 2021. Long term changes in paddy soil fertility in Peninsular Malaysia during 50 years after the Green Revolution with special reference to their physiographic environments. Soil Sci Plant Nutr, 67:80–88
Tanaka S, Yanai J, Nakao A, and Abe S, 2022. Summary of the Current Research and Implications for the Future, In "*Changes in Paddy Soil Fertility in Tropical Asia under Green Revolution, From the 1960s to the 2010s*, Chapter 10. Page 183-197", edited by Yanai J, Tanaka S, Nakao A, and Abe SS, Springer Nature Singapore Pte Ltd.
Toenniessen G, Adesina A and DeVries J. 2008. Building an Alliance for a Green Revolution in Africa, Ann. *New York Academy of Sci* 1136:233-242.
Vanlauwe B, Bationo A, Chianu J, Giller KE, Merckx R, Mokwunye U, Ohiokpehai O, Pypers P, Tabo R,
Seki H, 2016. Why was capitalism born in Europe? Re-question the history of the West and Japan (何故ヨーロッパで資本主義が生まれたか？西洋と日本の歴史を問い直す), NTT Publishing Co. Ltd. Tokyou, pp29
Sekine H and Umemoto M, 2015. Comparison of the factors responsible for the wheat yield gap between Japan and Germany 小麦収量水準格差の形成要因－日本とドイツの比較分析中央農研研究報告, 24：31 - 54（2015 Bull. NARO. Agric. Res. Center, https://www.naro.go.jp/english/laboratory/carc/files/Bull_NARC_24_3.pdf
Senoo K, Nasuda Y, Itohhideomi, Notaguchi M, Tabata R, Okayasu K, Sawai Y, Suzuki T, Kurotani K, Fuji M, Utami YD, Shimizu Y, Saijo Y, Ohmori Y, Fujiwara T, Shiratori Y, and Ota S, 2020. Ideal agriculture: Basic research and innovative crop production, Japanese Journal of Soil Science and Plant Nutrition, Vol.91(2):94-98(In Japanese)
Shepherd KD, Smaling EMA, Woomer PL, Sanginga N 2010. Integrated soil fertility management, Operational definition and consequences for implementation and dissemination, Outlook on Agriculture, 39: 17-28
Spencer DSC, 1991, file:///C:/Users/wakat/Downloads/S91ArtSpencerFarmingNothomNodev.PDF-63806d5b6fb6517b1b75b3236437c73b.pdf%20(1).pdf
Sustainable Development Solutions Network of A Global Initiative for the United Nations. 2013. Solutions for Sutainable Agriculture and Food Systems, Technical Report for the Post-2015 Development Agenda, pp108, http://unsdsn.org/wp-content/uploads/2014/02/130919-TG07-Agriculture-Report-WEB.pdf
Takeuchi K. 2010. Rebuilding the relationship between people and nature: the Satoyama Initiative. Ecolo Res (2010) 25:8791-897, DOI 10.107/s11284-010-0745-8, https://link.springer.com/article/10.1007/s11284-010-0745-8
The Morley, 2019. The Morley Agricultural Foundation and Morely Farms and Trials, Summary of our Activities, 1-19 pages.
Tsujimoto Y. 2015. Rice Ecology and SRI in Madagascar (In Japanese, Rice Cultivation in Asia and Africa, Horie T edded), Noson Gyoson Bunka Kyoukai, Tokyo, Chapter 7: 172-196
UNESCO, 2023. World heritage convention, Rice Terraces of the Philippine Cordilleras, https://whc.unesco.org/en/list/722/
Van Oost K and Six J, 2023. Reconciling the paradox of soil organic carbon erosion by water, Biogeosciences, 20, 635–646, 2023 https://doi.org/10.5194/bg-20-635-2023
Wakatsuki T and Azwar R, 1992, Rates of weathering and soil formation, Geoderma, 52 (1992) 251-263, http://kinki-ecotech.jp/download/WakatsukiRasydin1992Geoderma.pdf
Wakatsuki T, Azwar R, and Naganawa T, 1993. Multiple regression method for estimating rates of weathering and soil formation in watersheds, Soil Science and Plant Nutrition, 39:1, 153-159, https://doi.org/10.1080/00380768.1993.10416984

Wakatsuki T, 1997. Paddy (Sawah) Soil Science, In Latest Soil Science edited by Kyuma K, Chapter 10, pp157-178, Asakura Pub. Co. Ltd, Tokyo、最新土壌学、久馬一剛編、第 10 章、水田土壌学、朝倉書店

Wakatsuki T, 2002. Sustainable Agricultural Development of West Africa during Global Environmental Crises, In *Restoration of Inland Valley Ecosystems in West Africa*, edited by Hirose H and Wakatsuki T, Chapter 1:pp1-82 Nourin Tokei Kyoukai, Tokyo. p. 600. http://www.kinki-ecotech.jp/download/nourinntoukeikyoukai-chosho_EN/book_en_chapter1-4ed_20200212.pdf

Wakatsuki T, Evers A, Chen YS, Palada MC, Navasero NC, Fashola OO, Musa J, and Ashraf M. 1988. Effect of Improving the Paddy or Sawah Systems, Bida, Central Nigeria, IITA Resource & Crop Management Program, Annual Report 1986 : Chapter IV. Wetland Production Systems. P80-86, IITA Resource & Crop Management Program, Annual Report 1987 : Improvement of Rice-Based Systems, p182-191, http://www.kinki-ecotech.jp/download/IITAAnnualReport_1986-87_edit2May2014.pdf

Wakatsuki T, Shinmura Y, Otoo E and Olaniyan GO. 1998. African based *sawah* systems for the integrated watershed management of small inland valleys in West Africa. *In FAO Water Report No. 17. Institutional and Technical Options in the Development and Management of Small Scale Irrigation.* Rome, pp 45-60.

Wakatsuki T and Masuanga T. 2005. Ecological Engineering for Sustainable Food Production and the Restoration of Degraded Watersheds in Tropics of low pH Soils: Focus on West Africa. *Soil Sci Plant Nutr* 51:629-636.

Wakatsuki T, Buri MM and Oladele OI. 2009. West African green revolution by *sawah* ecotechnology and the creation of African Satoyama systems, *http://www.humanosphere.cseas.kyoto-u.ac.jp/article.php/workingpaper61*

Wakatsuki T, Buri MM, and Fashola OO. 2005. Ecological Engineering for sustainable rice production and the restoration of degraded watersheds in West Africa. In: *Rice is Life: Scientific Perspectives for the 21st Century*. Toriyama, K, Heong, KL and Hardey B. (eds), pp 363-366, IRRI, JIRCAS, NARO, NIAS, NIAES, NIRE, APO, MAFF, Tsukuba, Japan.

Wakatsuki T, Buri MM, Obalum SE, Bam R, Oladele OI, Ademiluyi SY and Azogu II. 2011. Farmers' personal irrigated *sawah* systems to realize the green revolution and Africa's rice potential, Paper presented at 1st International Conference on Rice for Food, Market, and Development (rice-Africa), Abuja, Nigeria March 3- 5.

Wakatsuki T, Otoo E, Andah WEI, Cobbina J, Buri MM and Kubota D. (eds). 2001a. Proceedings of the International Workshop on Integrated Watershed Management of Inland Valley-Ecotechnology Approach, 6th-8th February 2001, Novotel Accra, Ghana, http://www.kinki-ecotech.jp/download/2001WorkshopProceedingsAccra/2001FebWorkshopProceedingsAccra.pdf, 203p

Wakatsuki T, Otoo E, Andah WEI, Cobbina J, Buri MM and Kubota D. (eds). 2001b. *Integrated Watershed Management of Inland Valley in Ghana and West Africa: Ecotechnology Approach*, Final Report on JICA/CRI joint study project, CRI, Kumasi, Ghana and JICA, Tokyo, p. 337. http://www.kinki-ecotech.jp/download/JICA-CRI_Report2001/JICA%20CRI%202001%20Contents%20and%20Summary.pdf

Wakatsuki T, Buri MM, Bam R, Ademiluyi SY, and Azogu II 2013. Sawah Ecotechnology: Farmers' personal irrigated sawah systems to realize the Green Revolution and Africa's rice potential , http://www.kinki-ecotech.jp/

Wakatsuki T 2013a. Road map of the dissemination of irrigated Sawah development and Rice cultivation technology by African farmers' self-support efforts, Research for Tropical Agriculture, Vo.6:43-50 (in Japanese)

Wakatsuki T 2013b. http://www.kinki-ecotech.jp/

Wakatsuki T 2013c. Asian African Collaboration for Sustainable African Green Revolution through Sawah and Satoyama Eco-technology to Combat Global Food and Ecological Crisis in 2025" at 11th International Conference of ESAFS, 21-24 October 2013, Bogor, Indonesia

Weil Benedetto PW, Sikora LJ, and Bandel VA, 1988. "Influence of tillage practices on on phosphrous distribution and forms in three Ultisols," Agron. J., 80:503-509

Weinberg S, 2015, To explain the world: The discovery of modern science (Japanese translation by Akane Y and Oguri H, Bungei Shunjyu Publishing Co. Ltd, Tokyo, pp428)

World Bank 2016. Document of The World Bank Report No: ICR00003895, THIRD NATIONAL FADAMA DEVELOPMENT (FADAMA III) PROJECT, Nigeria, http://documents.banquemondiale.org/curated/fr/956751479735474649/text/FADAMA-III-ICR-P096572-Nov-2-2016-11162016.txt

Wopereis MCS, Diagne A, Rodenburg J, Sie M and Somado EA. 2008. Why NERICA is a successful innovation for African farmers: A response to Orr et al from the Africa Rice Center. *Outlook on Agric* 37:169-176.

Yagi K, Sriphiromu P, Cha-unu N, Fusuwankaya K, Chidthaisongu A, Damenb B and Towprayoonu S, 2020, Potential and promisingness of technical options for mitigating greenhouse gas emissions from rice cultivation in Southeast Asian countries, *SOIL SCIENCE AND PLANT NUTRIT10N*, VOL.66: NO 1:37-49, https://doi.org/10。1080/00380768。2019.1683890,

Yamazaki F, 1971. Agricultural land engineering, Vol.1. Irrigated Sawah Engineering (水田工学), 1-369page, University of Tokyo Press

Yanai J, Hirose M, Tanaka S, Sakamoto K, Nakao A, Dejbhimon K, Sriprachote A, Kanyawongha P, Lattirasuvan T, Abe S, 2020. Changes in paddy soil fertility in Thailand due to the green revolution during the last 50 years. Soil Sci Plant Nutr 66:889–899

Yanai J, Tanaka S, Nakao A, Abe SS, Hirose M, Sakamoto K, Masai F, Saito H, Kajiwara N,Dejbhimon K, Sriprachote A, Kanyawongha KP, Lattirasuvan T, Timbas N, Medina S, Paing TN, 8 Yusoff KHM, Wakatsuki T, and Kyuma K, 2021. Long-term changes in paddy soil fertility in tropical Asia after 50 years of the Green Revolution, Eur J Soil Sci. 2022;73:e13193. wileyonlinelibrary.com/journal/ejss 2021 British Society of Soil Science. 1 of 13, https://doi.org/10.1111/ejss.13193

Yanai J, Tanaka S, Nakao A, and Abe SS, 2022a. Comparison of Long-Term Changes in Paddy Soil Fertility Among Thailand, the Philippines, and Malaysia Based on the Original Data and the Factor Scores, In *"Changes in Paddy Soil Fertility in Tropical Asia under Green Revolution, From the 1960s to the 2010s,* Chapter 8. Page 141-160", edited by Yanai J, Tanaka S, Nakao A, and Abe SS, Springer Nature Singapore Pte Ltd. Singapore

Yanai J, Tanaka S, Nakao A, and Abe SS, 2022b. Changes in Paddy Soil Fertility in Tropical Asia under Green Revolution, From the 1960s to the 2010s, Springer Nature Singapore Pte Ltd. Singapore

Yeldu HM. 2014. Report on extension of sawah rice production technology in Kebbi state, 30th of May. Facilitator's report, Fadama III

Zhang L, Tian H, Shi H, Pan S, Chang J, Dangal SRS, Qin X,Wang S, Tubielio FN, Canadell JG, and Jackson RB, 2021. A 130-year global inventory of methane emissions from livestock: Trends, patterns, and drivers, *Glob. Change Biol.*, 2022;28:5142-5158, DC)1110,1111/gcb,16280,